PART IV:

STIS

STIS

Chapter 19
STIS Overview

In This Chapter...

This chapter provides an overview of the capabilities and design of STIS and describes the basic instrument operations. The material presented here is excerpted from the more complete information provided in the *STIS Instrument Handbook*, and we refer you there for more complete information about the properties of STIS as an instrument.

19.1 Instrument Capabilities and Design

The Space Telescope Imaging Spectrograph (STIS) was built by Ball Aerospace Corporation for the Goddard Space Flight Center (GSFC) Laboratory for Astronomy and Solar Physics, under the direction of Bruce Woodgate (GSFC), the Principal Investigator (PI). STIS has been performing very well since its installation during the second HST servicing mission in February 1997. A basic description of the instrument, and of its on-orbit performance through the Servicing Mission Orbital Verification (SMOV) program is provided by Kimble, et al. (1997, *ApJL*, in press). We encourage all STIS users to reference this paper, and to review the related papers in this special *ApJ Letters* which describe the Early Release Observations, and demonstrate the realized scientific capabilities of STIS. Long-slit and slitless image spectroscopy of galactic nuclei and SN1987A are described in Bower et al. (1997), Hutchings et al. (1997), and Sonneborn et al. (1997); medium- and high-resolution UV echelle spectroscopy of stars and the interstellar medium are described by Heap et al. (1997), Jenkins et al. (1997), and Walborn et al. (1997); Schultz et al. (1997) describe visible and near-IR spectroscopy of a brown dwarf near a much brighter companion; Pian et al. (1997) and Sahu et al. (1997) describe deep CCD imaging of a Gamma Ray Burst transient and of gravitational lens arclets, respectively; and Gardner et al. (1997)

describes the serendipitous detection of a high-redshift galaxy in a parallel observation.

STIS is a versatile instrument providing both imaging and spectroscopic capabilities with three two-dimensional detectors operating from the ultraviolet to the near-infrared. The optics and detectors have been designed to exploit HST's high spatial resolution. STIS has first order gratings, designed for spatially resolved long-slit spectroscopy over STIS's entire spectral range, and echelle gratings, available only in the ultraviolet, that maximize the wavelength range covered in a single spectral observation of a point source. The STIS Flight Software supports on-board target acquisitions and peakups to place science targets on slits and coronagraphic bars.

STIS can be used to obtain:

- Spatially resolved, long-slit or slitless spectroscopy from 1150–11,000 Å at low to medium spectral resolution (R ~ 400–14000) in first order.
- Echelle spectroscopy at medium to high spectral resolution (R ~ 23,500–100,000), covering a broad instantaneous spectral range ($\Delta\lambda$ ~800 or 250 Å, respectively) in the ultraviolet (1150–3100 Å).

In addition to these two prime capabilities, STIS also provides:

- A modest imaging capability using: the solar-blind far ultraviolet MAMA detector (1150–1700 Å); the solar-insensitive near ultraviolet MAMA detector (1700–3100 Å); and the optical CCD (2000–11,000 Å) through a small complement of narrow- and broad-band filters.
- Objective prism spectroscopy (R ~1000–26) in the vacuum ultraviolet (1200–3100 Å).
- High time resolution ($\Delta\tau$ = 125 microseconds) imaging and spectroscopy in the ultraviolet (1150–3100 Å) and moderate time resolution ($\Delta\tau$ ~10 seconds) CCD imaging and spectroscopy in the optical and near IR (2000–11,000 Å).
- Coronagraphic imaging in the optical and near IR (2000–11,000 Å) and bar-occulted spectroscopy over the entire spectral range (1150–11,000 Å).

See Table 19.1 on page 19-6 and Table 19.2 on page 19-7 for a complete list of grating and filters, respectively.

The STIS Detectors

STIS uses three large format (1024 x 1024 pixel) detectors:

- A Scientific Image Technologies (SITe) CCD, called the `STIS/CCD`, with 0.05 arcsecond square pixels, covering a nominal 51 x 51 arcsecond square field of view (FOV), operating from ~2000 to 11,000 Å.
- A Cs_2Te Multi-Anode Microchannel Array (MAMA) detector, called the `STIS/NUV-MAMA`, with 0.024 arcsecond square pixels, and a nominal 25 x 25 arcsecond square field of view (FOV), operating in the near ultraviolet from 1650 to 3100 Å.

- A solar blind CsI MAMA, the STIS/FUV-MAMA, with 0.024 arcsec pixels, and a nominal 25 x 25 arcsecond square FOV, operating in the ultraviolet from 1150–1700 Å.

The basic observational parameters of these detectors are summarized in Table 19.1 on page 19-6 and Table 19.2 on page 19-7.

The CCD provides high quantum efficiency and good dynamic range in the near-ultraviolet through near-infrared, and it produces a time integrated image in the so-called ACCUM data taking mode. As with all CCDs, there is noise (*read noise*) and time (*read time*) associated with reading out the detector. Time resolved work with this detector is done by taking a series of multiple short exposures. The minimum exposure time is 0.1 sec, and the minimum time between successive identical exposures is 37 seconds for full-frame readouts and 11 seconds for subarray readouts. CCD detectors are capable of high dynamic range observations, which are limited for a single exposure by the depth of the CCD full well, roughly ~120,000 to 170,000 e^- for the STIS CCD. This number is the maximum amount of charge (or counts) that can accumulate in any one pixel during any one exposure, without saturation. Cosmic rays affect all CCD exposures, and observers will generally want to CR-SPLIT their observations to allow cosmic ray removal in post-observation data processing.

The two MAMA detectors are *photon counting* detectors which provide a two-dimensional ultraviolet imaging capability. They can be operated either in ACCUM mode, to produce a time-integrated image, or in TIMETAG mode to produce an event stream with fast (125 μsec) time resolution. Doppler correction for the spacecraft motion is applied automatically on-board for data taken in ACCUM high spectral resolution modes.

The STIS MAMA detectors are subject to both *scientific* and *absolute* brightness limits. At high local (>50 count sec^{-1} $pixel^{-1}$) and global (>250,000 counts sec^{-1}) illumination rates, counting becomes nonlinear in a way that is not correctable. At only slightly higher illumination rates, the MAMA detectors are subject to damage.

STIS/ 19

STIS Physical Configuration

The STIS optical design includes corrective optics to compensate for HST's spherical aberration, a focal plane slit wheel assembly, collimating optics, a grating selection mechanism, fixed optics, and focal plane detectors. An independent calibration lamp assembly can illuminate the focal plane with a range of continuum and emission line lamps.

The *slit wheel* contains apertures and slits for spectroscopic use and the clear, filtered, and coronagraphic apertures for imaging. The slit wheel positioning is repeatable to very high precision: +/– 7.5 and 2.5 milli-arcseconds in the spatial and spectral directions, respectively.

The *grating wheel*, or Mode Selection Mechanism (MSM), contains the first-order gratings, the cross-disperser gratings used with the echelles, the prism, and the mirrors used for imaging. The MSM is a nutating wheel that can orient optical elements in three dimensions. It permits the selection of one of its 21 optical elements as well as adjustment of the tip and tilt angles of the selected grating or mirror. The grating wheel exhibits non-repeatability which is corrected in post-observation data processing using contemporaneously obtained comparison lamp exposures (i.e., wavecals).

For some gratings, only a portion of the spectral range of the grating falls on the detector in any one exposure. These gratings can be scanned (tilted by the MSM) so that different segments of the spectral format are moved onto the detector for different exposures. For these gratings a set of pre-specified central wavelengths, corresponding to specific MSM positions, i.e., grating tilts, have been defined.

STIS has two independent calibration subsystems, the HITM (Hole in the Mirror) system and the Insert Mechanism (IM) system. The HITM system contains two Pt-Cr/Ne line lamps, used to obtain wavelength comparison exposures and to illuminate the slit during target acquisitions. Light from the HITM lamps is projected through a hole in the second correction mirror (CM2), so light from the external sky still falls on the detector when the HITM lamps are used. The IM system contains flatfielding lamps and a single Pt-Cr/Ne line comparison lamp. When the IM lamps are used, the Calibration Insert Mechanism (CIM) is inserted into the light path, blocking all external light. Observers will be relieved to know that the ground system will *automatically* choose the right subsystem and provide the necessary calibration exposures.

19.2 Basic Instrument Operations

Target Acquisitions and Peakups

Once the telescope acquires its guide stars, your target will be within ~1–2 arcseconds of the aperture center. For science observations taken through slits less than three arcseconds in either dimension, and for science observations involving the coronagraphic bars, a target acquisition exposure is taken to center the target in your chosen science aperture and is followed by one or more peakup exposures to refine the target centering of point or point-like sources. Acquisition exposures always use the CCD, one of the filtered or unfiltered apertures for CCD imaging, and a mirror as the optical element in the grating wheel. Peakup exposures use a science slit or coronagraphic aperture, the CCD, and either a mirror or a spectroscopic element in the grating wheel.

Routine Wavecals

Each time the MSM is moved to select a new optical element or to tilt a grating, the resulting spectrum is projected onto the detector with an error (lack of repeatability) of roughly plus or minus 1 to 10 pixels (better for some modes and worse for others). In addition, thermal effects cause the spectrum to drift slowly with time (typical drifts are 0.1 pixels per orbit, extreme cases in the case of forced large temperature swings registered as high as 0.35 pixels per orbit). An internal calibration lamp observation (`WAVECAL`) is automatically taken following each use of a new grating element or new scan position (grating tilt) and every 40 minutes thereafter, in order to allow calibration of the zero point of the wavelength (dispersion) and spatial (cross dispersion) axes in the spectroscopic science data during post observation data processing. These routine, automatically-occurring, wavecal observations are expected to provide sufficient wavelength zeropoint accuracy for the large majority of GO science.

Data Storage and Transfer

At the conclusion of each exposure, the science data are read out from the detector in use and placed in STIS's internal buffer memory, where they are stored until they can be transferred to the HST data recorder (and thereafter to the ground). This design makes for more efficient use of the instrument, as up to seven CCD or four MAMA full frame images can be stored in the internal buffer at any time. The frames can be transferred out of the internal buffer to the data recorder during subsequent exposures, as long as those exposures are longer than three minutes.

STIS's internal buffer stores the data in a 16-bit per pixel format. This format imposes a maximum of 65,536 data numbers per pixel. For the MAMA detectors this number is equivalent to a limit on the total number of *photons* per pixel which can be accumulated in a single exposure. The CCD full well (and not the 16-bit buffer format) limits the photons per pixel that can accumulate without saturating in a single exposure, for both GAIN=1 and GAIN=4 observations.

Parallel Operations

STIS's three detectors do *not* operate in parallel—only one detector can be used at any time. Exposures with different STIS detectors can, however, be freely interleaved in an observing sequence, and there is no extra setup time or overhead in moving from one detector to another. The three detectors, sharing the bulk of their optical paths, also share a common field of view of the sky. STIS *can* be used in parallel with any of the other three science instruments on HST; however, use of the MAMA detectors in parallel is restricted.

Table 19.1: STIS Spectroscopic Capabilities

Grating	Spectral Range (Å) Complete	Spectral Range (Å) Per Tilt	Spectral Resolution Scale $\Delta\lambda$ (Å per pixel)	Spectral Resolution Resolving Power ($\lambda/2\Delta\lambda$)	# Prime Tilts[a]	Detector	Slits (apertures)[b, c, d, e]
CCD First Order Spectroscopy							
G750L	5240-11490	5030	4.92	535-1170	2	CCD	52X0.1 52X0.2 52X0.5 52X2 52X0.2F1
G750M	5450-11150	570	0.56	4870-9950	11	CCD	
G430L	2900-5700	2900	2.73	530-1040	1	CCD	
G430M	3025-5615	286	0.28	5330-10270	10	CCD	
G230LB	1685-3065	1380	1.35	615-1135	1	CCD	
G230MB	1635-3190	155	0.15	5550-10335	11	CCD	
MAMA First Order Spectroscopy							
G230L	1570-3180	1610	1.58	600-1150	1	NUV-MAMA	
G230M	1640-3175	90	0.09	9110-17500	19	NUV-MAMA	
G140L	1150-1736	610	0.60	935-1440	1	FUV-MAMA	
G140M	1145-1740	55	0.05	11500-17400	12	FUV-MAMA	
MAMA Echelle Spectroscopy							
E230M	1575-3110	800	λ/60,000	30000	2	NUV-MAMA	0.2X0.2, 0.2X0.06
E230H	1625-3150	267	λ/228,000	114000	6	NUV-MAMA	0.1X0.2, 0.1X0.09
E140M	1150-1735	620	λ/91,700	45800	1	FUV-MAMA	0.2X0.2, 0.2X0.06
E140H	1150-1700	210	λ/228,000	114000	3	FUV-MAMA	0.2X0.2, 0.2X0.09
MAMA Prism Spectroscopy							
PRISM	1150-3100	1950	1.2-120	1000-26	2	NUV-MAMA	25MAMA (clear)

a. Number of exposures at distinct tilts needed to cover spectral range of grating, with 10% overlap between spectra.
b. Naming convention gives dimensions in arcseconds of slit. For example `52X0.1` indicates the slit is 52 arcsec long in the cross-dispersion direction and 0.1 arcsec wide in dispersion. The `F` (e.g., in `52X0.2F1`) indicates that it is the fiducial on the bar which is specified for coronographic spectroscopy.
c. For the MAMA first order modes, only ~ 25 arcseconds of the long slit projects on the detector.
d. Full aperture clear (`50CCD` or `25MAMA`), longpass filtered (`F25QTZ` or `F25SRF2` in UV), and neutral density filtered slitless spectroscopy is also supported with the first order and echelle gratings. F25MGII is supported with E230H and E230M.
e. A 6 arcsec long slit (`6X0.2`) is also supported for use with the echelle gratings, but with order overlap.

Table 19.2: STIS Imaging Capabilities

Aperture Name	Filter	Central Wavelength (λ_c in Å)	FWHM ($\Delta\lambda$ in Å)	Field of View (arcsec)	Detector
Visible - plate scale ~0.05 arcseconds per pixel					
`50CCD`	clear	---	---	51x51	`STIS/CCD`
`F28X50LP`	optical longpass	λ>5500 Å		28x51	`STIS/CCD`
`F28X50OIII`	[OIII]	5007	5	28x51	`STIS/CCD`
`F28X50OII`	[OII]	3740	80	28x51	`STIS/CCD`
`50CORON`	clear + coronagraphic fingers	---	---	51x51	`CCD`
Ultraviolet - plate scale ~0.024 arcseconds per pixel					
`25MAMA`	clear	~1750-3100 Å ~1150-1700 Å		25x25	`STIS/NUV-MAMA` `STIS/FUV-MAMA`
`F25QTZ`	UV near longpass	λ > 1450 Å		25x25	`STIS/NUV-MAMA` `STIS/FUV-MAMA`
`F25SRF2`	UV far longpass	λ > 1280 Å		25x25	`STIS/NUV-MAMA` `STIS/FUV-MAMA`
`F25MGII`	MgII	2800	70	25x25	`STIS/NUV-MAMA`
`F25CN270`	continuum near 2700Å	2700	350	25x25	`STIS/NUV-MAMA`
`F25CIII`	CIII]	1909	70	25x25	`STIS/NUV-MAMA`
`F25CN182`	continuum near 1800Å	1820	350	25x25	`STIS/NUV-MAMA`
`F25LYA`	Lyman alpha	1216	85	25x25	`STIS/FUV-MAMA`
Neutral Density Filtered Imaging					

`F25NDQ1`
`F25NDQ2`
`F25NDQ3`
`F25NDQ4`
	neutral density filter, ND=10^{-1}
	neutral density filter, ND=10^{-2}
	neutral density filter, ND=10^{-3}
	neutral density filter, ND=10^{-4}
		{ 1150-11000 Å		12x12
				12x12
				12x12
				12x12
					`CCD`,
					`NUV-MAMA`,
					`FUV-MAMA`

`F25ND5`	neutral density filter, ND=10^{-5}	1150-11000 Å		25x25	
`F25ND6`	neutral density filter, ND=10^{-6}	1150-11000 Å		25x25	

Chapter 20

STIS Data Structures

In This Chapter...

This chapter explains how STIS observations are stored in STIS data files. When you receive STIS data files from the Archive, they will be in FITS format, and they should remain in FITS format (i.e., do not convert the format with **strfits**). Chapter 2 describes the structure of FITS files, explains how images and tables are stored in FITS extensions, and shows how to access data in these extensions. If you are not familiar with FITS extensions, please read Chapter 2 first.

20.1 Overview

Calibrated STIS data have been processed through the STScI **calstis** pipeline. The pipeline unpacks the databits from individual exposures, combines them into files containing raw, uncalibrated data, and performs image and spectroscopic reduction on the data to produce output files which can be used directly for scientific analysis (see Chapter 21 for a more detailed description of the STIS pipeline). Unlike previous HST pipelines, the STIS pipeline performs contemporaneous calibrations, processing data from multiple science exposures as well as contemporaneously obtained line lamp calibration exposures through the pipeline as a single unit. These multiple *associated* STIS exposures which are processed through the pipeline as a unit are combined into a single dataset, to allow easy identification and compact storage. (See Appendix B for a general explanation of HST data associations.)

To work effectively with your data you will need to understand:

- The basic format in which the STIS data are stored, the information and nature of the data stored for each observation—see "STIS File Structures", below.
- The nature of the individual files in your dataset, i.e., what data is stored in what file. Spectroscopic observers looking for the final calibrated product will want first to examine the `*_sx2.fits` or `*_x2d.fits` files, which store rectified, flux- and wavelength-calibrated, two-dimensional spectra, in the case of first order long slit data; or to examine the `*_sx1_fits` or `*_x1d.fits` files which store background subtracted, aperture extracted, flux- and wavelength-calibrated, one dimensional spectra, for the case of echelle spectroscopy—see "Types of STIS Files" on page 20-6.
- How to use the header keyword information to identify the principal parameters of your observation and to determine the calibration processing steps which were performed on your dataset—see "Headers, Keywords, and Relationship to Phase II" on page 20-9.
- The meanings of the error and data quality arrays, which are propagated through with each STIS science observation—see "Error and Data Quality Arrays" on page 20-13.
- How to use the STIS Paper Products—see page 20-15.

20.2 STIS File Structures

All STIS data products are FITS files. Images and two-dimensional spectroscopic data are stored in FITS image extension files, which can be directly manipulated, without conversion, in the IRAF/STSDAS environment. These FITS image extension files allow an *associated* set of STIS science exposures, processed through calibration as a single unit, to be packaged into a single file. Accessing the images in the FITS image extension files in IRAF follows a simple convention explained in detail in Chapter 2. The **catfits** task can be used to display the complete contents of the primary and extension headers of the data file. Section "Types of STIS Files" on page 20-6 describes the contents of these files and how to access them.

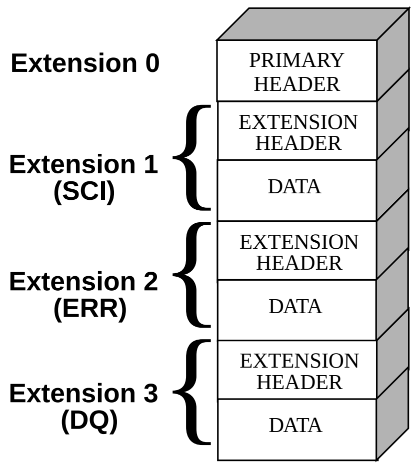
Tabular STIS information, such as extracted one-dimensional spectra or the `TIMETAG` mode event series are stored as three-dimensional FITS binary tables. The tables can be accessed directly in the IRAF/STSDAS environment using tasks in the **tables.ttools** package as described in Chapters 2 and 3.

20.2.1 STIS FITS Image Extension Files

Figure 20.1 illustrates the structure of a STIS FITS image extension file, which contains:

- A primary header that stores keyword information describing the global properties of all of the exposures in the file (e.g., the target name, target coordinates, total summed exposure time of all exposures in the file, optical element, aperture, detector, etc.).
- A series of image extensions, each containing a header with specific exposure-level keyword information only (e.g., exposure time, world coordinate system, etc.) and a data array.

Figure 20.1: FITS Image Extension File for STIS



Storage of STIS ACCUM Mode Science Data: Raw and Calibrated Two-Dimensional Spectroscopic and Imaging Data

All ACCUM mode uncalibrated science data from STIS and all calibrated STIS data, with the exception of the extracted one-dimensional spectra (see below) are stored in FITS image extension files with the particular format shown in Figure 20.1.

A triplet of FITS image extensions corresponds to each exposure in a STIS data file:

- The first, of extension type SCI, stores the science values.
- The second, of extension type ERR, contains the statistical errors, which are propagated through the calibration process.
- The third, of extension type DQ, stores the data quality values which flag suspect pixels in the corresponding SCI data.

The error arrays and data quality values are described in more detail in "Error and Data Quality Arrays" on page 20-13.

Two-Dimensional Extracted Spectra

The `rootname_sx2.fits`, `rootname_x2d.fits` files which hold the flux and wavelength-calibrated two-dimensional spectra for long-slit first-order observations are stored as FITS image, as are the raw data and the calibrated imaging data. The units of the data in the extracted two dimensional spectra are ergs sec^{-1} cm^{-2} A^{-1} $arcsec^{-2}$ $pixel^{-1}$. "Working with Two Dimensional Extracted Spectra" on page 23-3 describes how to work with these data to derive flux information and wavelengths.

Imaging Data

The final calibrated output product for CCD imaging data is the *rootname*`_crj.fits` file, and the final calibrated product for MAMA data is either the *rootname*`_flt.fits` or *rootname*`_sfl.fits files`. The units of the data in these files is in counts per pixel, just as in WFPC2 data, and in general these data can be manipulated just like WFPC2 data. See "Converting Counts to Flux or Magnitude" on page 3-15.

Storage of Acquisition and Acquisition/Peakup Images

Almost all STIS spectroscopic science exposures will have been preceded by an acquisition and possibly an acquisition/peakup exposure to place the target in the slit. Keywords in the header of spectroscopic data identify the dataset name of the acquisition (in the ACQNAME keyword) and acq/peak images (in the ACQPEAK1 and ACQPEAK2 keywords).

An acquisition exposure produces a raw data file (*rootname*`_raw.fits`) containing three science image extensions corresponding to the three stages of the acquisition procedure:

- [SCI,1] is a subarray image (100 x 100 for point source acquisitions; larger for diffuse acquisitions) of the sky obtained after the initial blind pointing.
- [SCI,2] is an image of the same subarray after the coarse locate phase of the acquisition.
- [SCI,3] is an image of the 32 x 32 subarray taken during the slit-illumination phase of the target acquisition.

An acquisition/peakup exposure will produce a single raw data file for a spiral search and one for each linear one-dimensional search (that is, if you have performed a peakup which requires LINEAR-AXIS1 and LINEAR-AXIS2 scans, then two data sets will be produced—one for each scan). The *rootname*`_raw` data file produced for an acq/peak exposure contains one science image extension:

- [SCI,1] is the confirmation image, taken at the end of the peakup, after the final move which places the target in the slit.
- To examine the flux values of the individual steps in the ACQ/PEAK, list the pixels (using the **listpix** task) of the fourth extension, i.e., *rootname*`_raw.fits[4]`.

20.2.2 Tabular Storage of STIS Data

Time-Tag

Time-tag event data is contained in a binary table extension in which each row of the table corresponds to a single event in the data stream and the columns of the table contain scalar quantities that describe the event, as shown in Table 20.1.

Table 20.1: Columns of a Time-Tag Data Table

Column Name	Units	Description
TIME	s	Elapsed time in seconds since the exposure start time
AXIS1	pixel	Doppler-corrected location of the event, AXIS1
AXIS2	pixel	Location of the event, AXIS2
DETAXIS1	pixel	Location of the event, raw AXIS1 (no Doppler correction applied)

The STIS pipeline collapses a time-tag event series into a single time-integrated image and processes it as if it were an ACCUM mode image. Outside of the pipeline the raw time-tag event stream can be manipulated to produce two-dimensional images which are integrated over user-specified times or manipulated directly (see “TIME-TAG Data” on page 23-5).

One-Dimensional Extracted Spectra

In the STIS pipeline, two-dimensional STIS echelle spectra are aperture extracted, order by order, and each extracted spectral order from a single spectral image is stored in a single table, one order per row. Each column of the table contains a particular type of quantity, such as wavelengths or fluxes. Table 20.2 shows the contents of the different columns in a STIS extracted spectrum table. Each table cell, corresponding to a particular spectral order and type of quantity, can contain either a scalar value or an array of values. For example, each cell in the WAVELENGTH column contains a one-dimensional array of wavelengths corresponding to a spectral order given by the scalar in the SPORDER column on the same row.

There will a separate table extension for each associated exposure in an associated set. For example, if you specified NEXP=3 on your proposal logsheet, you will find the extracted spectrum from the second exposure in the second table extension.

Table 20.2: Columns of a STIS Extracted Spectrum Table

Column Name	Contents	Units	Description
SPORDER	scalar		Spectral order number
NELEM	scalar		Number of valid elements in each array
WAVELENGTH	array	Angstroms	Wavelengths corresponding to fluxes
GROSS	array	counts s^{-1}	Extracted spectrum before subtracting BACKGROUND
BACKGROUND	array	counts s^{-1}	Background that was subtracted to obtain NET
NET	array	counts s^{-1}	Difference of GROSS and BACKGROUND arrays
FLUX	array	erg s^{-1} cm^{-2} A^{-1}	Flux calibrated NET spectrum
ERROR	array	erg s^{-1} cm^{-2} A^{-1}	Internal error estimate
DQ	array		Data quality flags

20.3 Types of STIS Files

The naming convention for STIS files is *rootname_xxx*.fits, where *xxx* is a three-character file suffix. The suffix identifies the type of data within the file. Table 20.3 lists the file suffixes for both uncalibrated and calibrated data files. Depending on the type of observation you have obtained, and therefore on the path it has taken through the calibration pipeline, you will find an appropriate subset of these files in your particular data set. Table 20.4 gives examples of typical STIS datasets for different types of observations. Shading indicates files most likely to be of use during data analysis.

20.3.1 Understanding Associations

A single FITS file will contain multiple science exposures whenever an *associated* set of science exposures is taken. Associations are created for target acquisitions, auto-wavecals, crsplits, and repeatobs (nexp=many in the RPS2 file). You can recognize a data file as an associated set for STIS because there will be a zero in the last position of the rootname (e.g., `o3tt01010_raw.fits`). The rootnames of the individual exposures in an associated data set are contained in the association file, which has suffix `_asn` (e.g., `o3tt01010_asn.fits`). An association file holds a single binary table extension, which can be displayed with the IRAF tasks **tprint** or **tread**. The information within an association table shows how the associated exposures are related. Figure 20.2 illustrates the contents of the association table for a CRSPLIT=2 observation, with an associated autowavecal.

Table 20.3: Data File Naming Conventions

Suffix	Type	Contents
		Unalibrated
`_raw`	image	Raw science[a]
`_tag`	table	Timetag event list
`_spt`	image	Support file (planning & telemetry information)
`_wav`	image	Associate wavecal exposure
`_wsp`	image	Wavecal support file (planning & telemetry information)
`_asn`	table	Association file
`_trl`	table	Trailer file (input)
`_lrc`	image	Local rate check image
`_lsp`	text	Local rate check support file
`_jit`	table	See Appendix C
`_jif`	image	See Appendix C
`_pdq`	table	See Appendix B
		Calibrated
`_flt`	image	Flatfielded science
`_crj`	image	Cosmic ray-rejected, flatfielded science
`_sfl`	image	Summed Flatfield ed science
`_x1d`	table	*1-D extracted spectra:* * aperture extracted, background subtracted, flux and wavelength calibrated spectra
`_x2d`	image	*2-D extracted data:* * rectified, wavelength and flux calibrated spectra or * geometrically corrected imaging data.
`_sx1`	table	Summed 1-D extracted spectra
`_sx2`	image	Summed 2-D extracted spectra
`_trl`	table	Trailer file (output); historical record of processing

a. Raw data from isolated wavecals, biases, darks, and flats, as well as from ACQs and ACQ/PEAKs, have the `_raw` suffix.

Table 20.4: Typical STIS Output Products by Observation Type

Observation Type	Uncalibrated Files	Calibrated Files
ACQ, ACQ/PEAK	`_raw`	none
IMAGING, ACCUM MODE, ASSOCIATED SET (crsplit or repeatobs)	`_raw, _spt, _asn, _trl`	`_flt, _crj, _sf1,` (MAMA only), `_crj` (CCD only)
IMAGING, ACCUM MODE, Single Exposure	`_raw, _spt, _asn, _trl`	`_flt`
FIRST ORDER SPECTROSCOPY, ACCUM MODE ASSOCIATED SET (crsplit or repeatobs)	`_raw, _wav, _asn, _spt, _wsp, _trl`	`_flt, _sx2, _crj`(CCD only) `_sx1` (CCD only)
FIRST ORDER SPECTROSCOPY, ACCUM MODE Single Exposure	`_raw, _wav, _asn, _spt, _wsp, _trl`	`_flt, _x2d`
ECHELLE SPECTROSCOPY, ACCUM MODE single exposure or ASSOCIATED SET	`_raw, _wav, _asn, _spt, _wsp, _trl`	`_flt, _x1d, _x2d`
TIMETAG IMAGING and SPECTROSCOPIC	`_tag` + ACCUM extensions	ACCUM extensions

Figure 20.2: Contents of Association Table

To display the association table for o3tt01010_asn.fits:

```
>tread o3tt01010_asn.fits
# row MEMNAME        MEMTYPE        MEMPRSNT
#
 1   O3TT01AVR        CRSPLIT           yes
 2   O3TT01AWR        CRSPLIT           yes
 3   O3TT01AXR        WAVECAL           yes
 4   O3TT01010        PRODUCT           yes
```

The association table above tells the user that the product, or data set, will have the rootname `o3tt01010`, that there will be two science exposures contained in the `o3tt01010_raw.fits` file which are CRSPLITS, and that a `o3tt01010_wav.fits` file should exist containing the contemporaneously obtained automatic wavecal. The `o3tt01010_raw.fits` file will contain six image extensions, one triplet of {SCI, ERR, DQ} for each exposure (see Figure 20.1). The pipeline will calibrate this data as a unit, producing a single cosmic ray rejected image (*rootname*`_crj.fits`) along with its data quality and error images as well as rectified spectra. Similarly, for `REPEATOBS` observations, in which many identical exposures are taken to obtain a time series, all the science data will be stored in sequential triplet extensions of a single FITS file. These will be processed through the **calstis** pipeline as a unit, with each image extension individually calibrated and the set of images also being combined to produce a total time-integrated, calibrated image. See Chapter 21 for more information about the pipeline processing.

20.4 Headers, Keywords, and Relationship to Phase II

As with previous HST instruments, the FITS header keywords in STIS data files store important information characterizing the observations and telemetry received during the observations and describe the post-observation processing of your dataset. Each keyword follows FITS conventions and is no longer than eight characters. Values of keywords can be integer, real (floating-point), or character string. Many are HST and STIS specific. Knowledge of the keywords and where to find them is an important first step in understanding your data. By examining your file headers, using either **infostis**, **catfits**, **imhead**, or **hedit**, you will find detailed information about your data including:

- Target name, coordinates, proposal id, and other proposal level information.
- Observation and exposure timing information such as observation start and duration.
- Instrument configuration information such as detector, grating, central wavelength setting, and filter.
- Readout definition parameters such as binning, gain, subarray parameters.
- Exposure-specific information such as more detailed timing, world coordinate system information, fine guidance sensor identification.
- Calibration information such as the calibration switches and reference files used by the pipeline and parameters derived from the calibration, such as image statistics, wavelength shifts.

The easiest way to quickly identify the observational parameters of a given dataset is to run the task **infostis** (see Figure 20.3 below) which prints selected header information for STIS FITS images. Wildcard characters or a file list may be used for input (e.g., `*.fits` or `@fitslist`).

Figure 20.3: Using infostis to Display Header Keywords

```
cl> infostis o3xi03a1m_raw.fits
--------------------------------------------------------------------------------
                                                S  T  I  S
--------------------------------------------------------------------------------

            Rootname: O3XI03A1M                    Detector: CCD
         Proposal ID: 7071                                 Obs Type: IMAGING
        Exposure ID: 3.031                              Obs Mode: ACQ
                                                                          Lamp: NONE
       Target Name: GD153-1                           Aperture: F28X50LP
 Right Ascension:  12:57:02.3                              Filter: Long_Pass
          Declination: +22:01:53.2               Opt Element: MIRVIS
               Equinox: 2000.0                              CCD amp: D
                                                                            Gain: 4
     Axis 1 binning: 1                                         CR-split: 1
     Axis 2 binning: 1
               Subarray: yes

   Total Exp. Time: 0.3 sec
 Number of imsets: 3
```

STIS/ 20

STIS takes CCD and MAMA spectroscopic and imaging data, as well as acquisitions and acq/peakups. The keywords relevant for one of these data types will not necessarily be relevant to another. Accordingly, you will find that the header on your particular file contains a unique combination of keywords appropriate for your type of observation. Long definitions for the keywords can also be accessed from the following Web page, which provides detailed explanations of the contents and algorithm for populating the keywords. This site also provides sample headers for different STIS file types:

`http://archive.stsci.edu/keyword`

Keywords that deal with a particular topic, such as the instrument configuration, are grouped together logically throughout the headers. Table 20.5 lists a useful subset of these groups of keywords, indicates the name of the grouping, and where applicable, shows their relationship to the corresponding information from the Phase II proposal.

Table 20.6 summarizes the possible calibration switch keywords, and indicates whether they are present for a particular observation; it also indicates the reference file keyword corresponding to the particular calibration step. A calibration switch keyword is populated with one of OMIT, COMPLETE, or PERFORM. Similarly, Table 20.7 summarizes the reference file group of keywords that identify the files used by the pipeline during calibration (see Chapter 21 for a detailed description of pipeline processing).

Table 20.5: Selected Keywords and Relationship to Phase II

Keyword	Phase II Equivalent	Description
NEXTEND		Number of image extensions in the file.
	Target Information (Primary Header)	
TARGNAME	Target Name	Name of target.
RA_TARG	RA Position	Right ascension of the target (deg) (J2000).
DEC_TARG	DEC	Declination of the target (deg) (J2000).
	Proposal Information (Primary Header)	
PROPOSID		4 digit proposal number
LINENUM		Indicates the visit and exposure number from the phase II proposal; format vv-nnnn, visit number, exposure num..
	Summary Exposure Information (Primary Header)	
TDATEOBS		UT date of start of first exposure in file (a character string)
TTIMEOBS		UT start time of first exposure in file (a character string); primary header.
TEXPSTRT		Start time (MJD) of 1st exposure in file (a real number).
TEXPEND		End time (MJD) of last exposure in the file (a real number); primary header.
TEXPTIME	Time_per_Exposure	Total exposure time (a real number); summed for an association; primary header.

Table 20.5: Selected Keywords and Relationship to Phase II (Continued)

Keyword	Phase II Equivalent	Description
	Science Instrument Configuration (Primary Header)	
OBSTYPE		Observation type (IMAGING or SPECTROSCOPIC).
OBSMODE	Opmode	Operating mode (ACQ,ACQ/PEAK,ACCUM,TIME-TAG).
DETECTOR	Config	Detector in use: NUV-MAMA, FUV-MAMA, or CCD.
OPT_ELEM	Sp_Element	Optical element in use (grating name or mirror).
MIRROR	Sp_Element	Mirror element used for imaging observations.
CENWAVE	Centra_Wavelength	Central wavelength for grating settings.
APERTURE	Aperture	Aperture name.
FILTER	Derirved from Aperture	Filter in use.
APER_FOV		Aperture field of view.
WAVEMIN		Minimum wavelength of the data.
WAVEMAX		Maximum wavelength of the data.
PLATESC		Plate scale (arcsec/pixel).
SCLAMP		Lamp status, NONE or name of lamp which is on.
LAMPSET		Spectral cal lamp current value (milliamps).
NRPTEXP	Number_of_Iterations	Number of repeat exposures in set: default 1.
SUBARRAY		Data from a subarray (T) or full frame (F).
CRSPLIT	CR-SPLIT (optional parameter)	Number of cosmic ray split exposures.
	Readout Definition Parameters	
SIZAXIS1	SIZEAXIS1	Subarray axis 1 size in unbinned detector pixel.
SIZAXIS2	SIZEAXIS2	Subarray axis 2 size in unbinned detector pixel.
BINAXIS1	BINAXIS1	Axis 1 data bin size in unbinned detector pixel.
BINAXIS2	BINAXIS2	Axis 2 data bin size in unbinned detector pixel.
CCDAMP		CCD amplifier read out (A,B,C,D).
CCDGAIN	GAIN (optional parameter)	Commanded gain of CCD.
CCDOFFST		Commanded CCD bias offset.
ATODGAIN		Calibrated CCD amplifier gain value.
	Exposure Information (Extension header only)	
DATE-OBS		UT date of start of observation (dd/mm/yy); extension header.
TIME-OBS		UT time of start of observation (hh:mm:ss); extension header.
PA_APER		Position angle of slit.
ORIENTAT		Position angle of detector.
CRPIX et al.		
DGESTAR		FGS ID(F1,F2,F3) concat. w/ dom. gd. star id.

Table 20.6: Calibration Switch Keywords

Keyword	Ref. File Keywords	Explanation	Spectra	Images	CCD	MAMA
STATFLAG	N/A	Calculate image statistics?	•	•	•	•
DQICORR	BPIXTAB	Initialize data quality image	•	•	•	•
LORESCORR	N/A	Convert MAMA image to low-res	•	•		•
DARKCORR	DARKFILE	Dark image correction	•	•	•	•
FLATCORR	LFLTFILE PFLTFILE DFLTFILE	Flatfield corrections	•	•	•	•
SGEOCORR	SDSTFILE	Small-scale distortion correction	•	•	•	•
RPTCORR	N/A	Add individual repeat observations	•	•	•	•
ATODCORR	ATODTAB	A-to-D correction	•	•	•	
BLEVCORR	N/A	Correct for CCD bias level (overscan)	•	•	•	
BIASCORR	BIASFILE	Bias image (structure) correction	•	•	•	
CRCORR	CRREJTAB	Cosmic ray rejection	•	•	•	
EXPSCORR	N/A	Process individual observations after CRCORR	•	•	•	
SHADCORR	SHADFILE	Shutter shading correction	•	•	•	
PHOTCORR	PHOTTAB	Populate header photometric keywords		•	•	•
GEOCORR	N/A	Geometric correction		•	•	•
X2DCORR	SDCTAB DISPTAB INANGTAB APDESTAB MOFFTAB SPTRCTAB	Rectify 2-D spectral image	• • • • • •		• • • • • •	• • • • • •
X1DCORR	SPTRCTAB XTRACTAB	Extract 1-D Spectrum	•		•	•
BACKCORR	XTRACTAB	Subtract spectral background	•		•	•
DISPCORR	DISPTAB INANGTAB APDESTAB MOFFTAB	Apply dispersion solution	•		•	•
WAVECORR	N/A		•		•	•
FLUXCORR	APERTAB PHOTTAB	Convert to absolute flux	•		•	•
HELCORR	N/A	Convert to heliocentric wavelengths	•			•
DOPPCORR	N/A	Doppler correction needed? (TIMETAG mode only)	•			•
GLINCORR	N/A	Global detector non-linearities	•			•
LFLGCORR	N/A	Flag pixels for local and global non-linearities	•			•

Table 20.7: Reference File Keywords

Keyword	File Suffix	Format	Explanation	Spectra	Images	CCD	MAMA
BPIXTAB	_bpx	Table	Bad pixel	•	•	•	•
ATODTAB	_a2d	Table	A-to-D correction	•	•	•	
CCDTAB	_ccd	Table	CCD parameters	•	•	•	
BIASFILE	_bia	Image	Bias (structure)	•	•	•	
CRREJTAB	_crr	Table	Cosmic ray rejection parameters	•	•	•	
SHADFILE	_ssc	Image	Shutter shading correction	•	•	•	
DARKFILE	_drk	Image	Dark	•	•	•	•
LFLTFILE	_lfl	Image	Low-order flat	•	•	•	•
PFLTFILE	_pfl	Image	Pixel-to-pixel flat	•	•	•	•
DFLTFILE	_dfl	Image	Delta-flat	•	•	•	•
SDSTFILE	_ssd	Image	Small-scale distortion correction	•	•		•
MLINTAB	_lin	Table	Flux linearity table	•	•		•
PHOTTAB	_pht	Table	Photometric conversion	•	•	•	•
APERTAB	_apt	Table	Aperture throughput	•		•	•
LAMPTAB	_lmp	Table	Template CAL lamp spectra	•		•	•
APDESTAB	_apd	Table	Aperture descriptions	•		•	•
IDCTAB	_idc	Table	Image distortion correction		•	•	•
SDCTAB	_sdc	Table	2-D spectrum distortion correction	•		•	•
INANGTAB	_iac	Table	Incident angle correction	•		•	•
MOFFTAB	_moc	Table	MAMA Offset correction	•			•
DISPTAB	_dsp	Table	Dispersion coefficients	•		•	•
SPTRCTAB	_1dt	Table	1-D Spectrum trace	•		•	•
XTRACTAB	_1dx	Table	1-D Extraction parameter	•		•	•

20.5 Error and Data Quality Arrays

The STIS pipeline propagates both statistical errors and data quality flags throughout the calibration process, combining, appropriately, the statistical errors and data quality flags from both the science data and the reference file data so as to produce triplets of science, error and data quality in the calibrated data and extracted spectra.

Note that both the error and data quality image extensions may be represented with a null array (i.e., NAXIS=0 following STScI conventions) if all the values are identically zero (see Table 20.8). See also *STIS ISR* 95-006.

20.5.1 The Error Array

The error array contains an estimate of the statistical error at each pixel. In the raw file, the error array is empty. The first step of **calstis** is to calculate the error array for the input data. This raw data error is simply given as:

$$\sigma_{DN} = \frac{\sqrt{\sigma_c^2 + R \cdot g}}{g} \qquad \text{Eq. 20.1}$$

where

- *R* is the observed data number (counts) minus the electronic bias of the pixel, which is zero for the MAMA.
- *g* is the gain factor which is set to unity for MAMA observations.
- σ_c is the white noise component, which is the readnoise in electrons for CCD observations, and is set to zero for MAMA observations.

The bias, gain factor, and readnoise are read from the CCD parameters reference file for CCD data. As the data are calibrated through the **calstis** pipeline,the statistical errors are propagated through, reflecting both the science and reference file errors.

20.5.2 Data Quality Flagging

Data quality flags are assigned to each pixel in the data quality extension. Each flag has a true (set) or false (unset) state. Flagged conditions are set as specific bits in a 16-bit integer word; in this way up to 15 data quality conditions can be flagged simultaneously for a single pixel, using the bitwise logical OR operation. Note that the data quality flags cannot be interpreted simply as integers but must be converted to base 2 and interpreted as flags. Table 2.4 gives the specific conditions which are flagged by the different bits being on or off.

The raw data quality files will be filled only when there is missing (datalost) or dubious (softerr) data. If no such errors were taken, generic conversion will produce an empty data quality file whose header has NAXIS=0.

These flags are set and used during the course of calibration, and may likewise be interpreted and used by downstream analysis applications.

Table 20.8: STIS Data Quality Flags

FLAG Value	Bit Setting	Quality Condition Indicated
1	0000 0000 0000 000**1**	Reed solomon decoding error.
2	0000 0000 0000 00**1**0	Lost data replaced by fill values.
4	0000 0000 0000 0**1**00	Bad detector pixel (e.g., bad column or row, mixed science and bias for overscan, or beyond aperture).
8	0000 0000 0000 **1**000	Data masked by occulting bar.
16	0000 0000 000**1** 0000	Pixel having dark rate > 5 sigma times the median dark level.
32	0000 0000 00**1**0 0000	Large blemish, depth > 40% of the normalized p-flat. Applies only to FUV-MAMA repeller wire at present.
64	0000 0000 0**1**00 0000	Reserved.
128	0000 0000 **1**000 0000	Reserved.
256	0000 000**1** 0000 0000	Saturated pixel, count rate at 90% of max possible—local non-linearity turns over and is multivalued; pixels within 10% of turnover and all pixels within 4 pixels of that pixel are flagged
512	0000 00**1**0 0000 0000	Bad pixel in reference file.
1024	0000 0**1**00 0000 0000	Small blemish, depth between 0.4 and 0.7 of the normalized flat. Applies only to MAMA p-flats at present.
2048	0000 **1**000 0000 0000	>30% of background pixels rejected by sigma-clip, or flagged, during 1-D spectral extraction.
4096	000**1** 0000 0000 0000	Extracted flux affected by bad input data.
8192	00**1**0 0000 0000 0000	Data rejected in input pixel during image combination for cosmic ray rejection.
16384	0**1**00 0000 0000 0000	Reserved.

20.6 STIS Paper Products

A routine product of the calibration pipeline is the post-calibration *paper products* that summarize the data obtained. Guest Observers (GO) will receive these automatically a few weeks after their data are taken. Archival observers can recreate these paper products by retrieving all of the science and jitter data for a particular observation and using the STSDAS **pp_dads** task (at the IRAF prompt type: `pp_dads *.fits`).

STIS paper products are designed to summarize a set of exposures, for a single visit. A given page in the STIS paper product falls into one of two categories: a visit-level page or an exposure-level page. Below we list the individual pages contained in the STIS paper products; Figure 20.4 through Figure 20.7 provide samples of several of the paper products pages. Users are encouraged to read *STIS ISR* 97-11, which provides much more detail about the STIS paper products.

Visit-level Pages

- ***Cover Page***: A cover page containing the proposal ID, the visit number, the PI’s name, and the proposal title.
- ***Explanatory Notes*** (Figure 20.4): A set of notes explaining the paper products and the information they contain.
- ***Target List*** (Figure 20.5): A table listing the targets in the set of observations being summarized.
- ***Observation List***: A table recapping the proposal information for each exposure for the set of observations being summarized, including three processing and data quality flags.
- ***Optional Parameters***: A table listing the proposal-level optional parameters for the set of observations being summarized.
- ***Statistics***: A table of simple statistics for the set of observations being summarized to allow for a quick comparison among observations.

Exposure-level Pages

- ***Exposure Plots***: A graphical representation of the data contained in each exposure. Plots are specific to a particular instrument configuration and observing mode. In some cases, more than one plot is produced. The types of exposure plots are: ACQ image plot (Figure 20.6), ACQ/PEAK image plot, image plot (Figure 20.7), Rectified two-dimensional spectral image plot, one-dimensional extracted spectrum plot, time-series plot, and local rate check image plot.
- ***Data Quality Summary***: A comprehensive summary of the spacecraft performance, pipeline processing status, and calibration data quality for each exposure.
- ***Calibration Reference File Summary***: A summary of the calibration processing switches and reference files used to process each exposure.

Figure 20.4: Explanatory Notes

STIS

Description of Visit Summaries

Target List

The Target List contains the target name, the coordinates for the target as calculated by the ground system based on the target information taken from the proposal, and the text description of the target given in the proposal. Note that the coordinates listed represent the predicted position of the target in the sky and do not give the pointing of HST at the time of the observation.

Observation List with Data Quality Flags

The Observation List contains information that uniquely identifies individual exposures as specified in the observing proposal. Additionally, the status of the spacecraft and ground system performance during the execution of the observations are summarized by the Procedural Quality Flags:

- OBS — Status of the performance of HST.
- PROC — Status of the pipeline processing of the observations.
- CAL — Status of the reference data used in calibration.

Symbols used to indicate the status of the Procedural Quality are:

- ○ — OK.
- ● — Not OK-Refer to the Data Quality Summary for details.
- Blank — Status unknown.

Observation List-Optional Parameters

The Observation List contains additional instrument configuration information. Entries in the table reflect the values of the Optional Parameters specified in the observing proposal.

Observation Statistics

This Observation Statistics table contains a simple set of statistics of the raw (or flat-fielded) data for the observations.

Description of Exposure Summaries

Plots for Each Exposure

Plots are created for each exposure. Grey-scale or line plots are produced as appropriate for the instrument configuration and observing mode for each exposure. Exposure information taken from the headers of the data files is also provided.

Data Quality Summary for Each Exposure

The Data Quality Summary contains details of problems flagged by the Data Quality flags. Exposure information taken from the headers of the data files is also provided.

Calibration status summary for each exposure

The calibration summary gives detailed information about the calibration of the observations. Individual calibration steps are listed with completion status. Reference files used are listed by name and information about the pedigree of the calibration data is provided.

Need Help?

Send e-mail to your contact scientist or help@stsci.edu

Figure 20.5: Target List

Visit: 03 Proposal: 7505 STIS

Target List

Target Name	R.A. (J2000)	Dec. (J2000)	Description
IO-ADO	21:38:15.84	-14:58:30.0	[N/A]
NONE	0:00:00.00	0:00:00.0	[N/A]

Observation List

Visit-Exp#	Rootname	Target Name	Detector	Operating Mode	Aperture	Optical Element	Cenwave (Å)	Total Exp Time (s)	# of Exp	File	Quality Flags Obs	Proc	Cal
3.010	[illegible]	IO-ADO	CCD	ACCUM	F28X50LP	MIRVIS	[N/A]	0.1	1	flt		○	○
3.020	[illegible]	IO-ADO	CCD	ACQ	F28X50LP	MIRVIS	[N/A]	0.1	1	raw		○	N/A
3.030	[illegible]	IO-ADO	CCD	ACCUM	F28X50LP	MIRVIS	[N/A]	0.1	1	flt		○	○
3.040	[illegible]	NONE	CCD	ACCUM	52X0.2	G750L	7751	36.0	2	flt		○	○
3.050	[illegible]	IO-ADO	CCD	ACCUM	52X0.2	G750L	7751	24.0	2	crj		○	○
3.070	[illegible]	IO-ADO	CCD	ACCUM	52X0.2	G750L	7751	24.0	2	crj		○	○
3.080	[illegible]	IO-ADO	CCD	ACCUM	52X0.2	G750L	7751	24.0	2	crj		○	○
3.090	[illegible]	IO-ADO	CCD	ACCUM	52X0.2	G750L	7751	24.0	2	crj		○	○
3.100	[illegible]	NONE	CCD	ACCUM	52X0.2	G750L	7751	36.0	2	flt		○	○
3.160	[illegible]	NONE	CCD	ACCUM	52X0.2	G750M	8561	150.0	2	flt		○	○
3.170	[illegible]	IO-ADO	CCD	ACCUM	52X0.2	G750M	8561	36.0	2	crj		○	○
3.180	[illegible]	IO-ADO	CCD	ACCUM	52X0.2	G750M	8561	36.0	2	crj		○	○
3.200	[illegible]	IO-ADO	CCD	ACCUM	52X0.2	G750M	8561	36.0	2	crj		○	○
3.210	[illegible]	IO-ADO	CCD	ACCUM	52X0.2	G750M	8561	36.0	2	crj		○	○
3.220	[illegible]	NONE	CCD	ACCUM	52X0.2	G750M	8561	150.0	2	flt	●	○	○

Figure 20.6: ACQ Plot

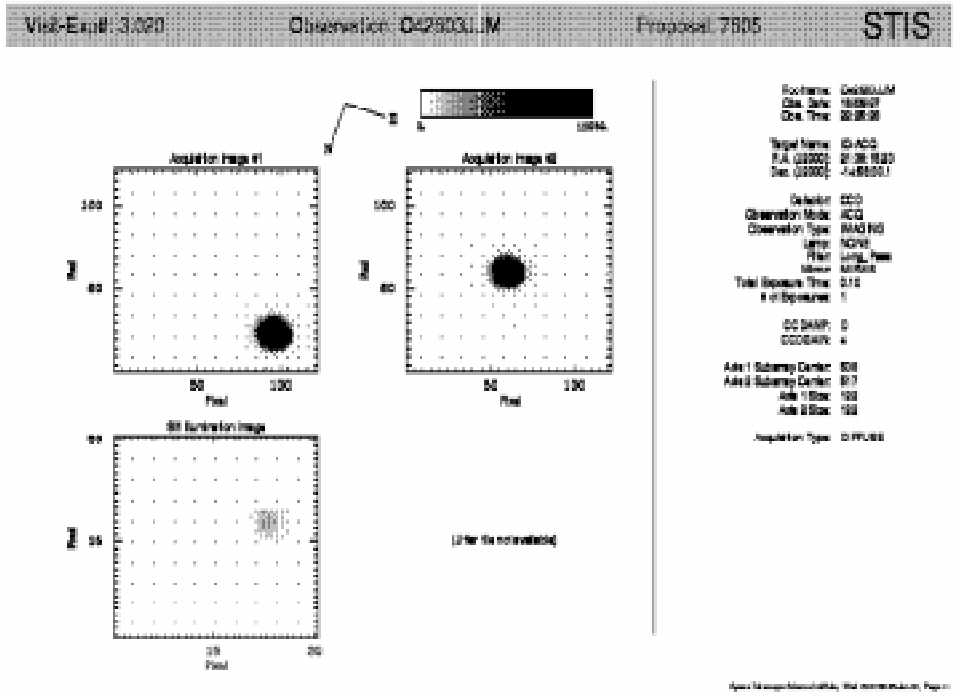
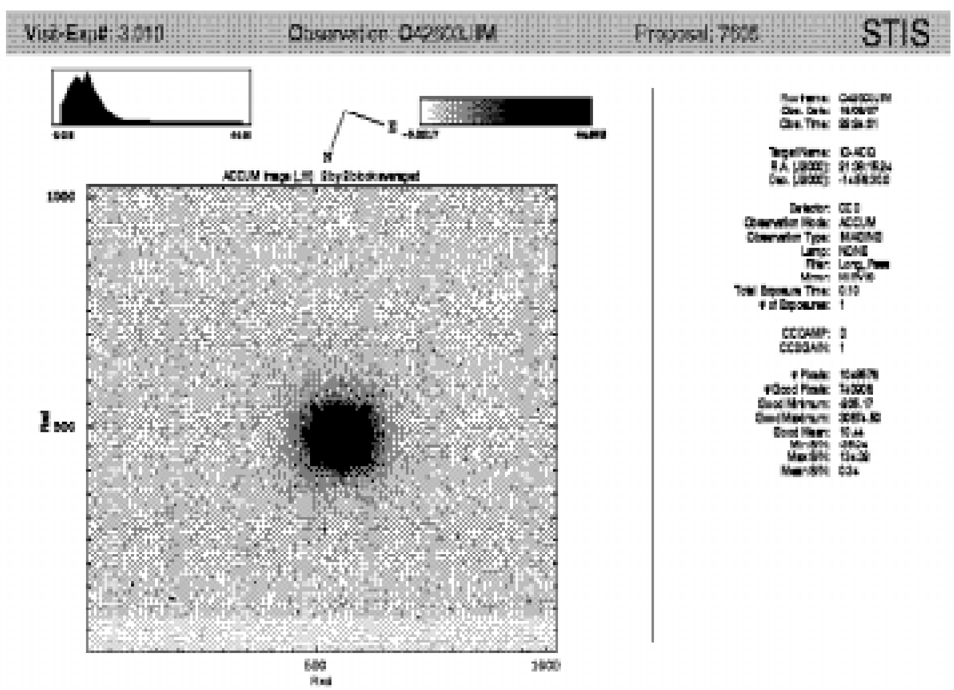


Figure 20.7: Image Plot



Chapter 21
STIS Calibration

In This Chapter...

This chapter describes how the STIS pipeline at STScI calibrates incoming STIS data. We begin with a high-level overview of the STIS calibration process, and subsequent sections describe the pipeline calibration steps and methodology in successively greater detail. We then discuss several reasons why you might want to recalibrate your data, and how to use the pipeline tasks for recalibration.

21.1 Pipeline Processing Overview

Science data obtained with STIS are received from the Space Telescope Data Distribution Facility and sent to the STScI pipeline, which unpacks the data, extracts keywords from the telemetry stream, reformats the data, and repackages them into raw, uncalibrated, but scientifically interpretable data files. The raw files are then calibrated, and the output files are stored in the Hubble Data Archive. What is described in this chapter is **calstis**, the program that performs the calibration of the science data and is available to the community as part of the STSDAS package.

Conceptually, **calstis** is several pipelines in one, reflecting the complexity and diversity of STIS observing modes. Your STIS data will have been calibrated to different levels, depending on their nature:

- ACQs, ACQ/PEAKs, and all available-mode data are not calibrated by **calstis**; you will get only the raw data from observations taken in these modes.

- All other science data are processed through basic two-dimensional image reduction (**basic2d**), which includes such things as bias subtraction, dark subtraction, flatfielding, and linearity correction. In the case of CCD CR-SPLIT or REPEATOBS data, your data will also be passed through cosmic ray rejection.
- All spectroscopic data (exclusive of slitless spectra or long slit echelle data) are then passed through spectroscopic reduction, to produce flux and wavelength calibrated science data. In the case of long slit data, a two-dimensional rectified image is produced. In the case of echelle data, a one-dimensional background subtracted aperture extracted spectrum is produced.
- Data taken in TIMETAG mode are output both as a raw uncalibrated event stream (to a FITS binary table), and as an ACCUM mode image which then passes through standard calibration.
- For MAMA data, the input raw data format is 2048 x 2048 (so called "high-res" pixels), while the calibrated data are binned by the pipeline to 1024 x 1024 native format pixels (see "LORSCORR" on page 21-22).

See Chapter 20 for the naming conventions of the various input, intermediate, and output calibrated files.

As with the calibration pipelines for the other HST instruments, the specific operations that are performed during calibrations are controlled by *calibration switches*, which are stored in the image headers as `keyword=value` pairs. Any given step in the calibration process may require the application of zero, one, or more *calibration reference files*, the names of which are also found in the image header. The names of the keywords containing the switches and reference file names were introduced in the previous chapter, and the section "Data Flow Through calstis" on page 21-9 will discuss them in detail. It is important to realize that only the calibration-related keywords that are relevant to the particular observation mode will appear in any given data header. Likewise, the path your data files take through the pipeline is determined by the calibration switches set in the header of the raw data, which in turn depends directly on the type of data you have.

A few other general comments are in order. STIS differs from earlier HST instruments in that some of the calibration reference data are obtained contemporaneously with the science observations. These data may be used to refine the calibration process (as with the automatic wavecals), or may require you to replace a default calibration reference file with a contemporaneously obtained one, as in the case of a CCD near infrared (NIR) fringe flat. The details of how these contemporaneous calibration files are used in **calstis** can be found in "Descriptions of Calibration Steps" on page 21-15. The STIS (and NICMOS) pipelines are also unusual in that they are re-entrant. That is, a user running **calstis** off-line may elect to reprocess STIS data partially, performing one or more of the intermediate steps without re-exercising the complete **calstis** pipeline, for instance to perform cosmic-ray rejection, or one dimensional spectral extraction. Refer to "Recalibration of STIS Data" on page 21-30 for the mechanics (and restrictions) of this kind of processing. Finally, as with other HST pipelines, **calstis** propagates statistical errors and tracks data quality flags throughout the calibration process.

21.2 Structure of calstis

Calstis consists of a series of individual modules which:

- Orchestrate the flow through the pipeline.
- Perform basic two-dimensional image reduction.
- Reject cosmic rays from CCD data.
- Process the contemporaneously obtained wavecal data to obtain the zeropoint shifts in the spectral and spatial directions.
- Perform spectroscopic calibration, with wavelength and flux calibration.
- Perform final processing.

Table describes in more detail the individual modules in **calstis** and what they do. The IRAF task that can be used to run a particular segment of the pipeline independently is also provided (see “Rerunning Subsets of the Calibration Pipeline” on page 21-34).

Below we present a series of flow charts which provide a more complete overview of the processing of data through the **calstis** pipeline, starting with the fundamental step of two-dimensional image reduction.

The first step is to reduce the data through flatfielding and reject cosmic rays or co-add the data as appropriate. Figure 21.1 shows the route taken by CCD and MAMA data.

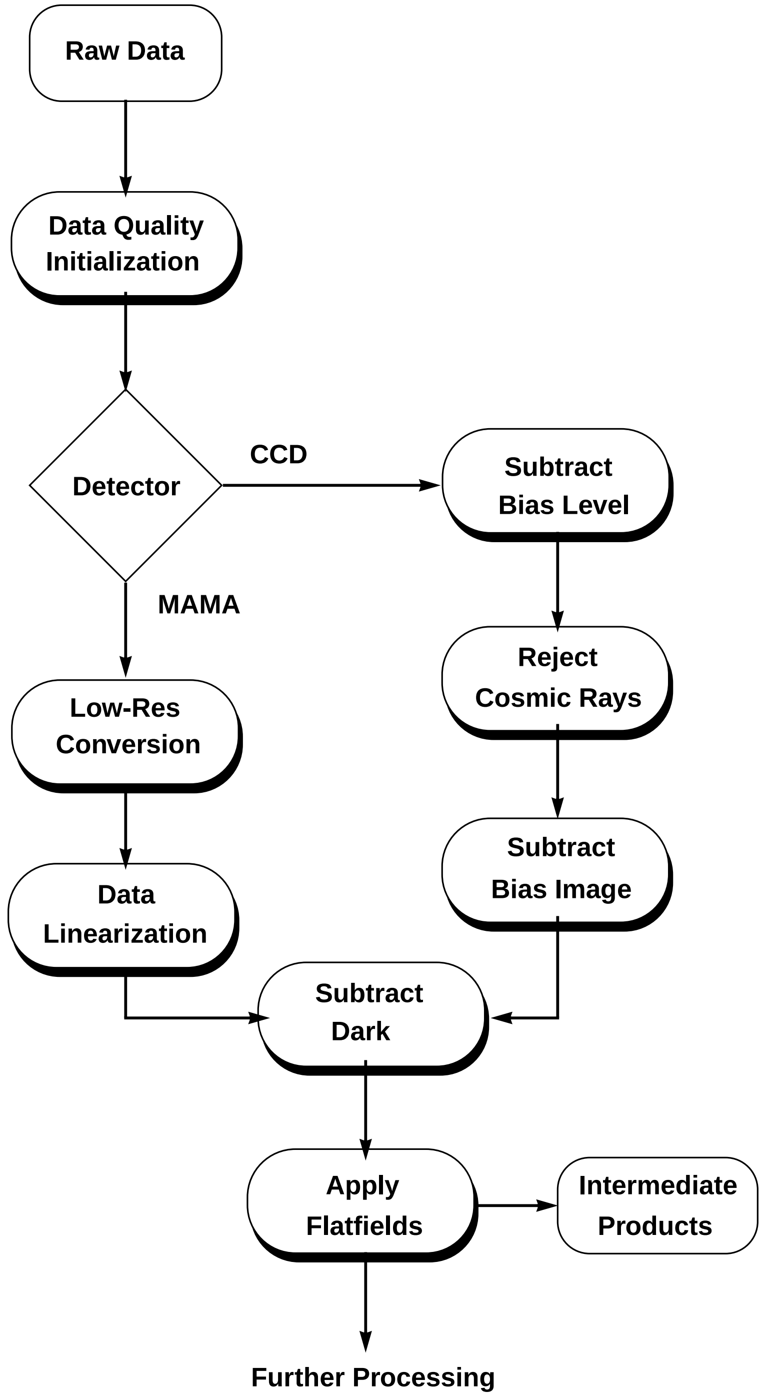
Table 21.1: Calstis Module Description Summary

IRAF Task	Description of Processing Step	Module[a]
	Full Pipeline	
calstis	**"Wrapper" program calls each of the calstis tasks as needed**, according to the switches set in the *primary header* of the input file. The **calstis** constituent tasks can instead be executed independently when recalibrating.	*calstis0*
	Basic 2-D image Reduction	
basic2d	**Basic 2-D image reduction**. This step includes overscan subtraction, bias subtraction, dark subtraction, flatfield ing, initializing the data quality array from the bad-pixel table, assigning values to the error array, and computing some simple statistics. Normally, cosmic-ray rejection is applied during the course of basic image processing; however, **basic2d** can be customized to omit this step and to limit processing to overscan subtraction.	*calstis1*
	Cosmic Ray Rejection	
occreject	**Detect and remove cosmic rays in CCD data**. When multiple images at the same pointing have been taken, this module identifies cosmic rays (optionally flagging them in the input file) and co-adds the input images, writing one output image without cosmic rays.	*calstis2*
	Contemporaneous Wavecal Processing	
wavecal	**Determine MSM offset from wavecal**. This step is used in conjunction with calstis7, calstis11, and calstis12. Its purpose is to find the offset of the spectrum from the expected location, owing to nonrepeatability of the mode select mechanism. The shift is written into the SCI extension header of the input wavecal image.	*calstis4*
	Subtract science image from wavecal. For CCD wavecal observations taken with the HITM system, the detector is exposed to both the wavecal and the science target. This task reads both the wavecal and science files and subtracts the science data from the wavecal. Following this step , calstis4 can be used to determine the spectral shift.	*calstis11*
	Write spectral shift value to science header. A series of science images (i.e., CRSPLIT or REPEATOBS) and wavecals may have been taken, with the wavecals interspersed in time among the science images. For each image in the science file, this task selects the wavecal in the wavecal file that is closest in time to the science image, and it copies the keyword values for the spectral shift from that wavecal header to the science header.	*calstis12*
	Spectroscopic Calibration and Extraction	
x1d	**1-D spectral extraction**. This task is most appropriate for echelle data or for a long-slit observation of a point source. A spectrum is extracted along a narrow band, summing in the cross-dispersion direction and subtracting nearby background values to produce a 1-D array of fluxes for each spectral order. D are not resampled in the dispersion direction; instead, an array of wavelengths is generated. Each output spectrum is written to a separate row of a FITS binary table, together with the arrays of the gross, net, and background count rates.	*calstis6*
x2d	**2-D rectification**. This task performs geometric correction for imaging data, or for long-slit spectroscopic data it extracts a 2-D spectrum linear in both wavelength and spatial directions.	*calstis7*
	Final Processing	
	Sum repeatobs data. If multiple MAMA images were taken and combined into one input FITS file, this task can be used to add them together, pixel by pixel. This task would not normally be used for CCD data because they would already have been combined for cosmic ray rejection.	*calstis8*

a. Referenced in the trailer file.

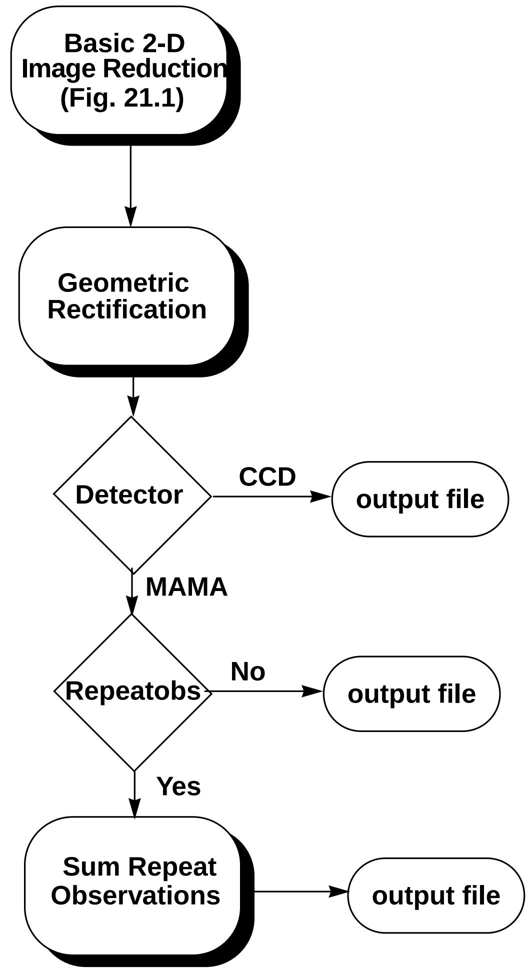
STIS/ 21

Figure 21.1: Basic 2-D Image Reduction (First Step in Subsequent Flowcharts)



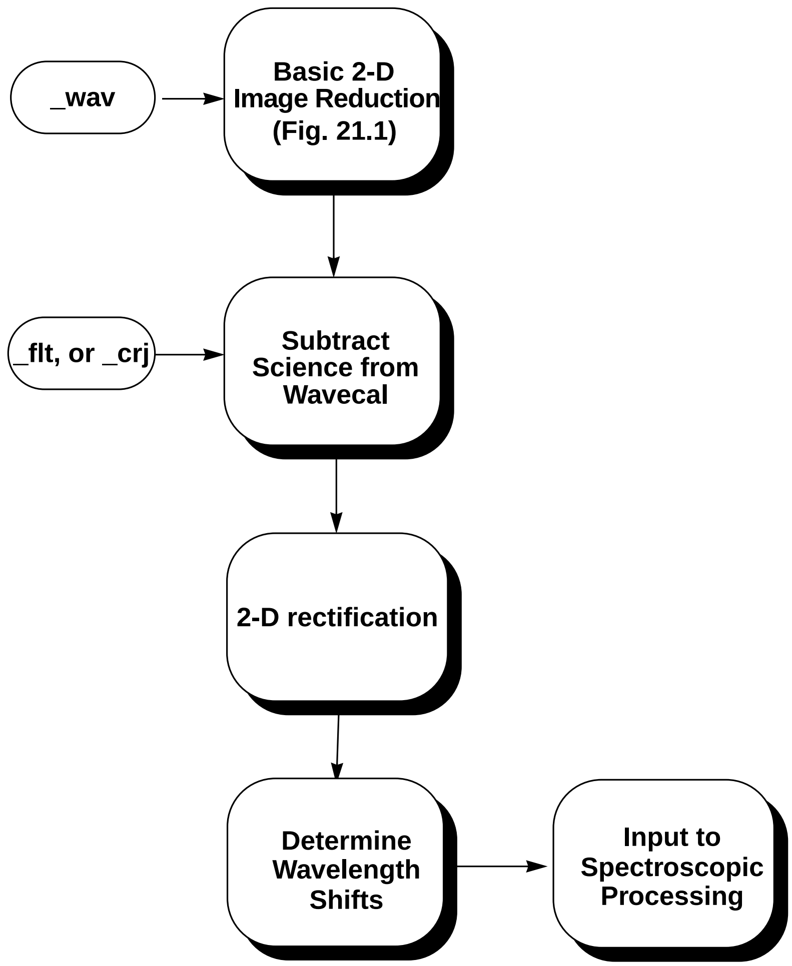
The calibration beyond the basic 2-D image processing depends upon whether the data are obtained in imaging or spectroscopic mode, as illustrated in Figure 21.2. The primary operations are geometric correction and photometric calibration, and a summation of multiple MAMA exposures if NRPTEXP > 1. The output is a geometrically rectified image with header keywords that specify the photometric calibration. When geometric correction is not applied, the output will be photometrically calibrated flatfielded data with suffix `_crj`, `_flt`, or `_sfl`.

Figure 21.2: Schematic of calstis for Secondary Image Processing



For spectroscopic exposures, **calstis** will process the associated wavelength calibration (wavecal) exposure to determine the zero point offset of the wavelength and spatial scales in the science image, thereby correcting for the lack of repeatability of the mode select mechanism (MSM) or for thermal drift. The accompanying wavecal observations are stored in the *rootname*`_wav.fits` file.

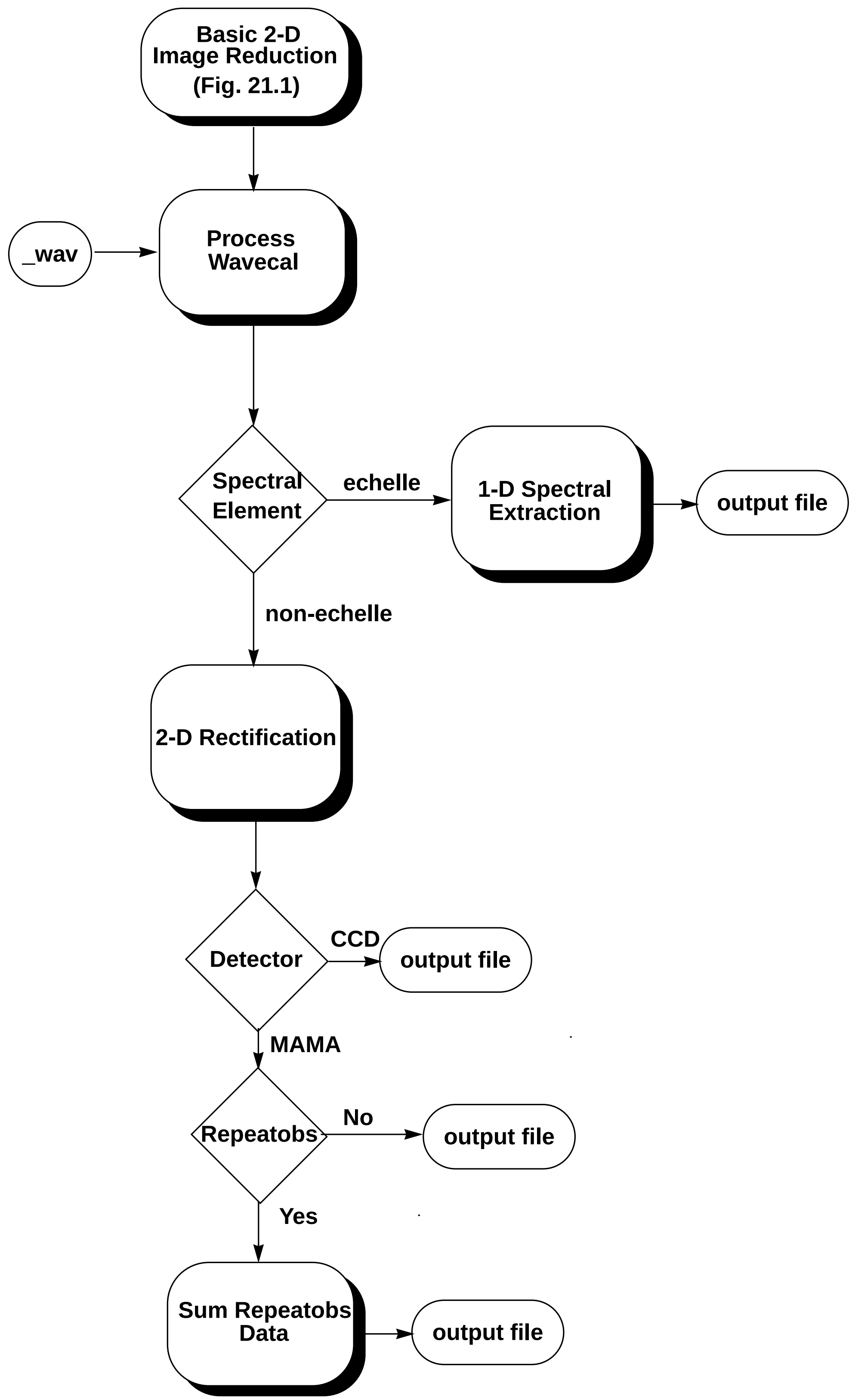
Figure 21.3: Schematic of calstis for Contemporaneous Wavecals



Two-dimensional spectral processing produces a flux-calibrated, rectified spectroscopic image with distance along the slit running linearly along the *y* axis and dispersion running linearly along the *x* axis.

One-dimensional spectral extraction produces a one-dimensional spectrum of flux versus wavelength (`rootname_x1d.fits`), uninterpolated in wavelength space, but integrated across an extraction aperture in the spatial direction. This extraction is currently performed only for echelle short slit observations in the pipeline. Future enhancements will perform the extraction for point sources in all first-order modes as well.

Figure 21.4: Schematic of calstis for Spectroscopic Data



21.3 Data Flow Through calstis

This section details the data flow through the **calstis** pipeline for each calibrated operating mode, showing the switches, the reference file inputs, the science file inputs and the output products. The next section describes the tasks corresponding to the various calibration switches.

Figure 21.5: 2-D CCD Image Reduction Process

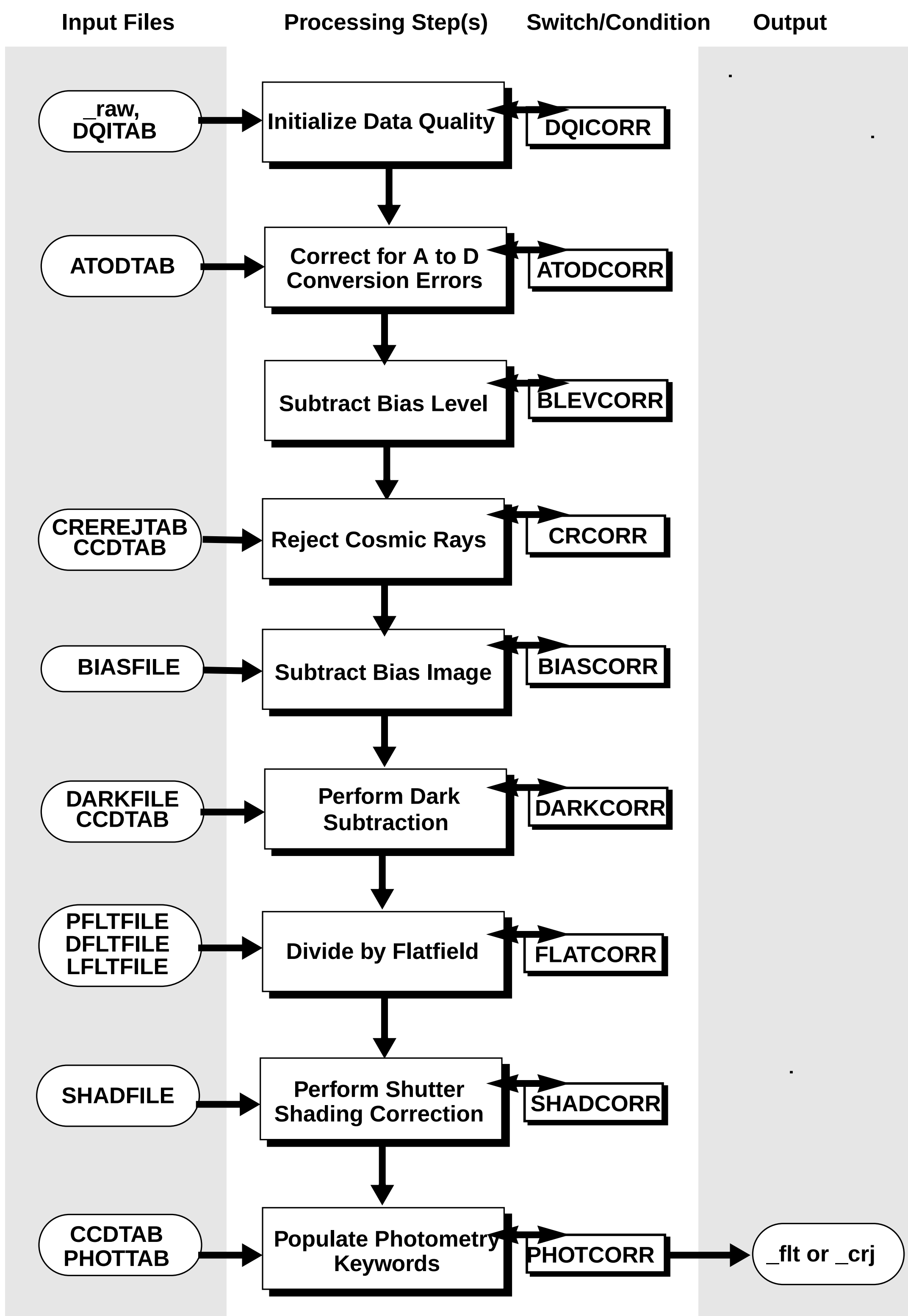


Figure 21.6: 2-D MAMA Image Data Reduction Process

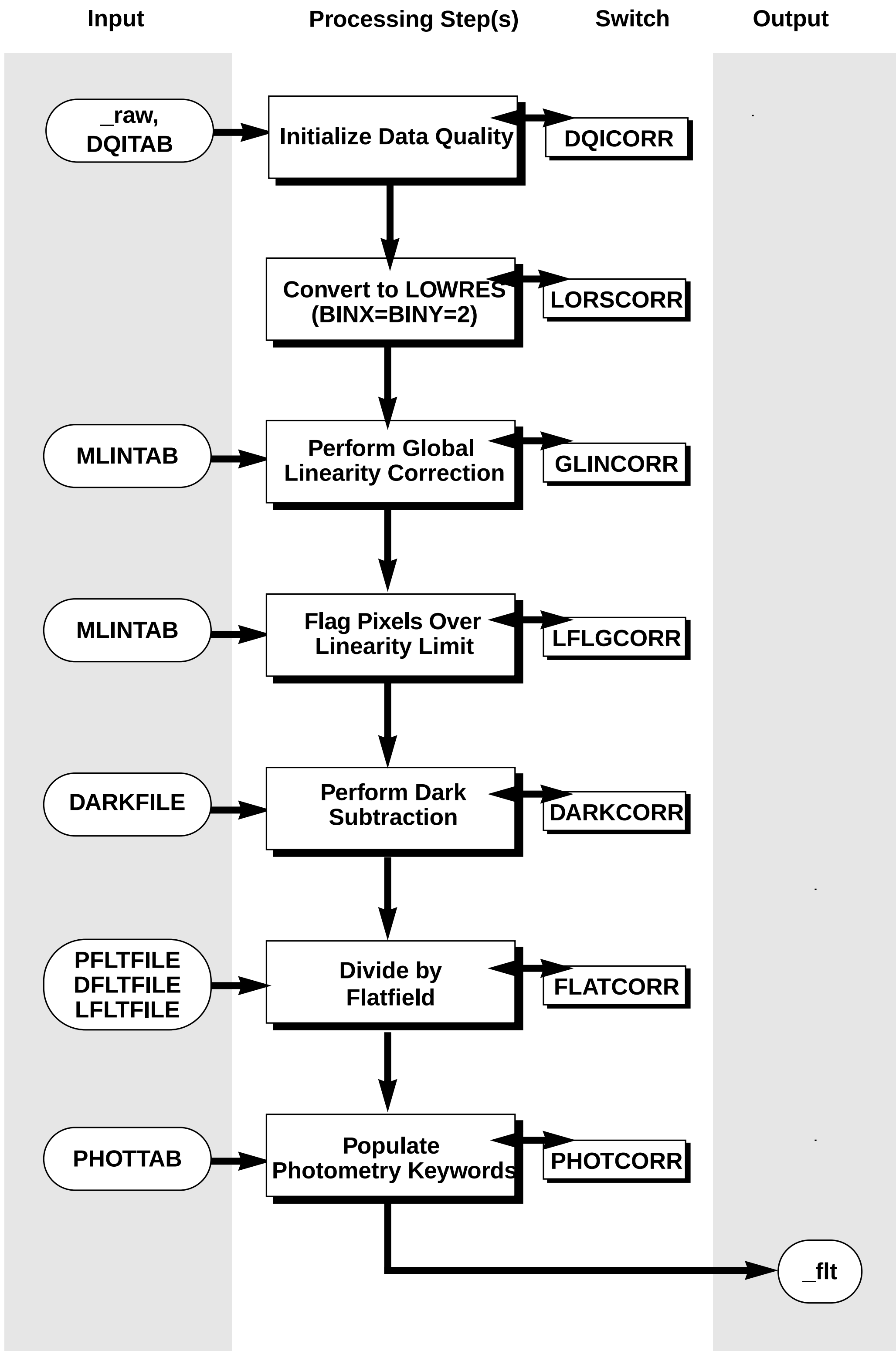


Figure 21.7: Calstis-4, wavecal Processing

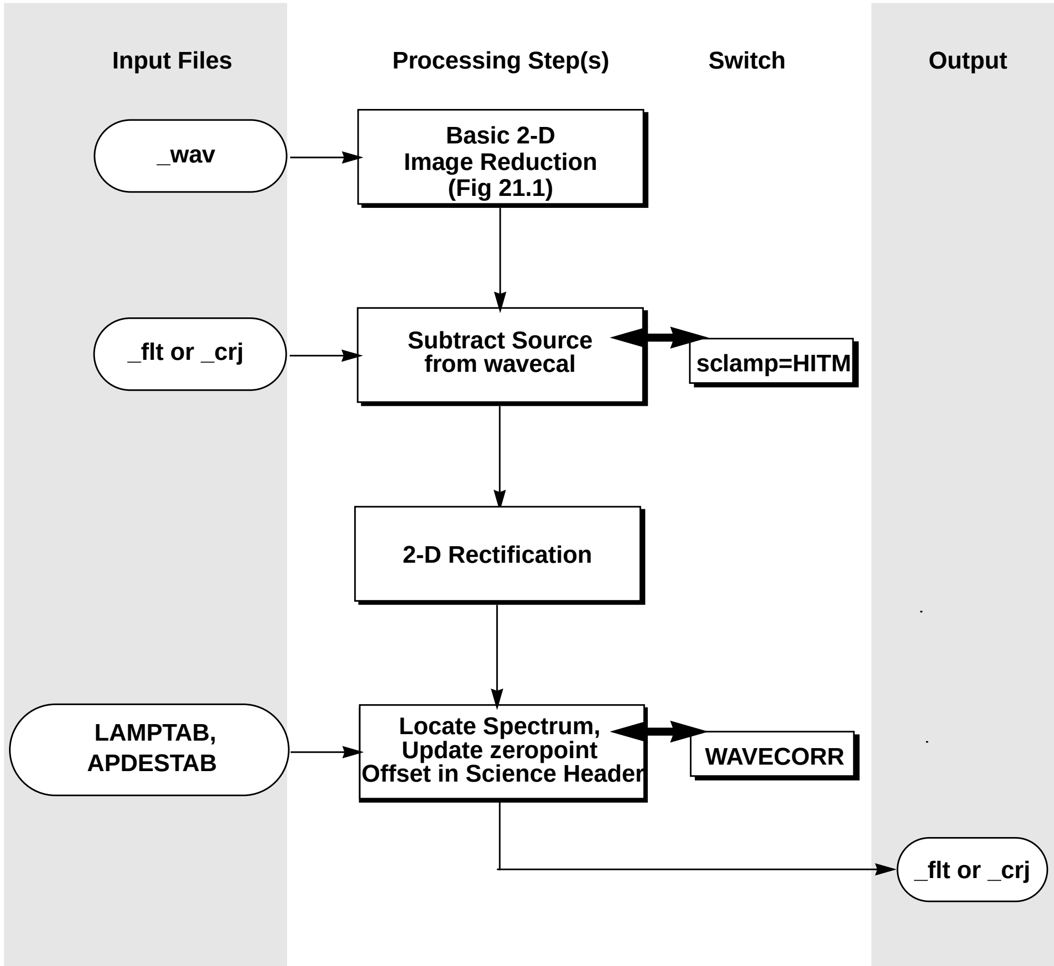


Figure 21.8: Flow Through calstis-6, 1-D Extraction.

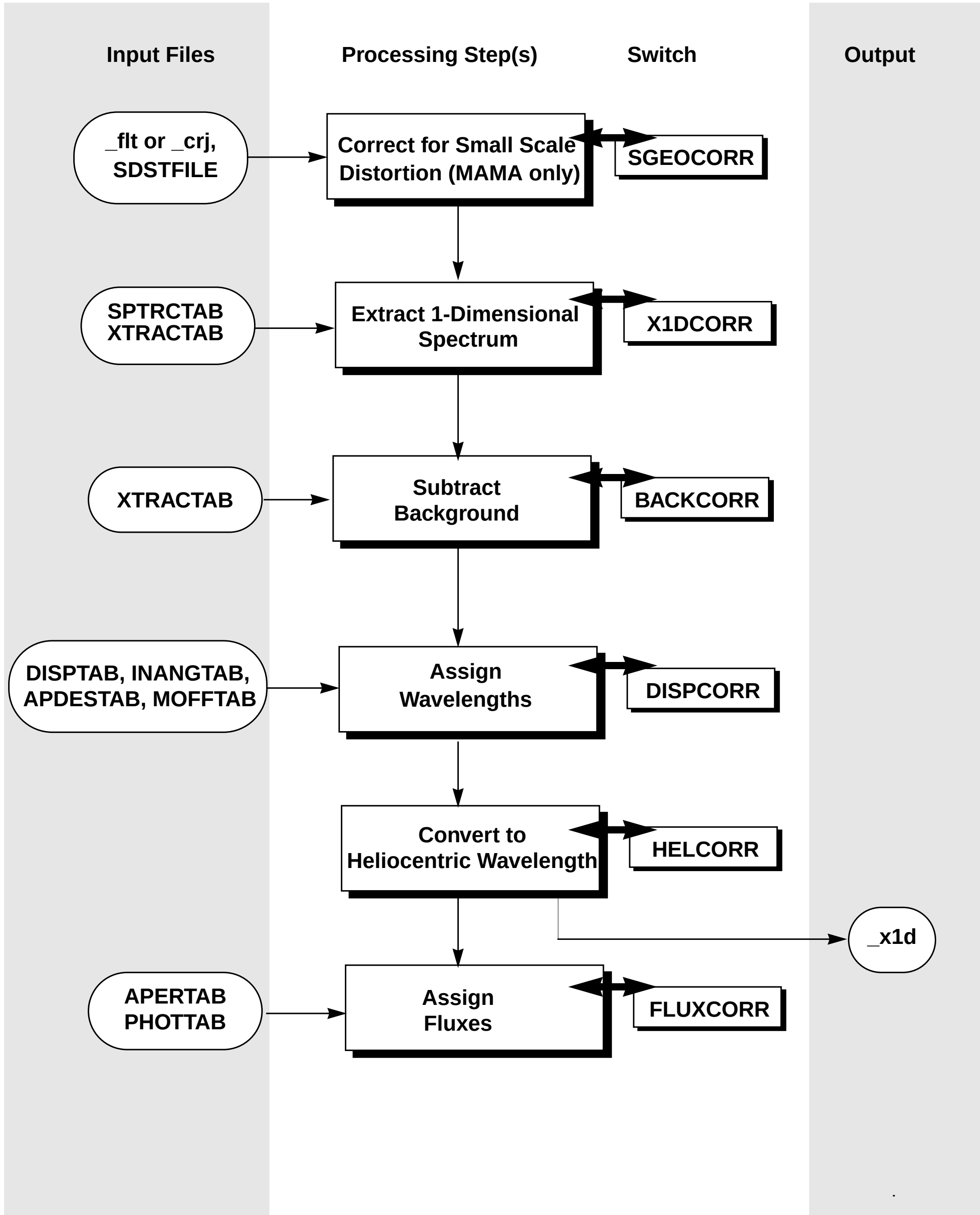


Figure 21.9: Flow Through calstis-7, 2-D Rectification

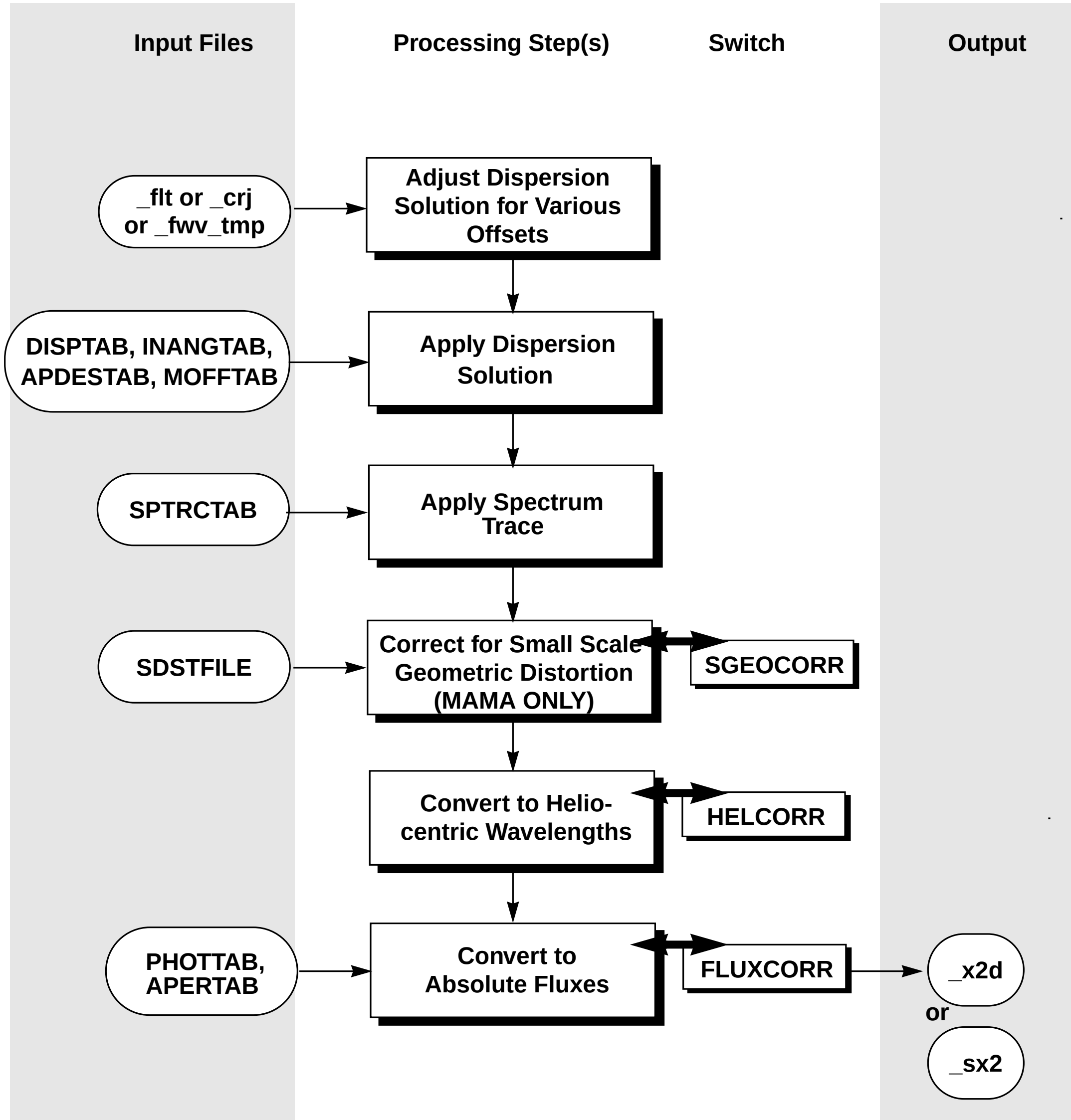
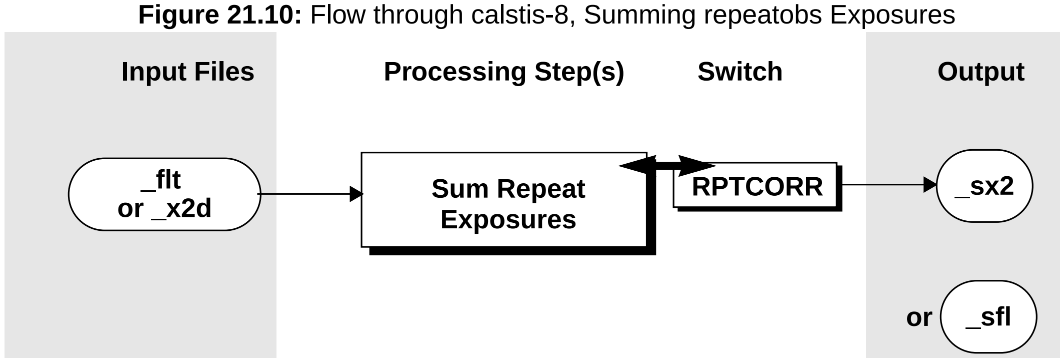


Figure 21.10: Flow through calstis-8, Summing repeatobs Exposures



STIS/ 21

21.4 Descriptions of Calibration Steps

In this section we provide a more detailed description of the algorithms applied by **calstis**. As always, a given step will be performed on your data if the corresponding calibration switch in the input data was set to PERFORM (see Chapter 2). The algorithmic descriptions below are described according to the major component of the **calstis** pipeline in which they are used, namely:

- Two-dimensional image reduction, including basic 2-D reduction, cosmic ray rejection and image co-addition.
- Processing of the contemporaneously obtained wavecal.
- Two-dimensional and one-dimensional spectral extraction, with flux and wavelength calibration.

Within each component, the individual steps are listed alphabetically, because the order in which they are performed can change for different types of data (e.g., CCD or MAMA, spectroscopic or imaging, CR-SPLIT or not).

More detailed descriptions can be found in a series of *Instrument Science Reports* (ISRs) that discuss the pipeline. Be aware, however, that while these reports describe the original design of the pipeline and the associated algorithms in detail, they do not always contain information concerning later modifications. Over time these reports will be updated to include a more complete description of the pipeline. In the meantime we refer you to the STIS WWW page, where a history of the important changes to the **calstis** pipeline code is maintained.

21.4.1 Two-Dimensional Image Reduction

ATODCORR

This applies only to CCD data. An analog to digital correction would be applied if the CCD electronic circuitry which performs the analog to digital conversion were biased toward the assignment of certain DN (data number) values. Ground test results show that this correction is not currently needed, so the ATODCORR switch will always be set to OMIT.

BIASCORR

This step is performed only for CCD data. The BIASCORR step removes any two-dimensional additive stationary pattern in the electronic zeropoint of each CCD readout after the BLEVCORR step is applied. To remove this pattern a bias reference image is subtracted. The bias reference file (BIASFILE) is a full-format *superbias* image created from many bias frames to assure low noise. If the science image is a subarray or is binned, a section of the bias image is extracted and binned to match the science image, prior to bias subtraction. If a CCD gain other than one is used, the bias reference file is scaled by the gain factor from the CCDTAB reference table prior to subtraction. The bias image has an associated data quality image extension: bad pixels in the bias image are flagged in the science data quality image.

BLEVCORR

This step is performed only for CCD data. The BLEVCORR step subtracts the electronic bias level for each line of the CCD image and trims the overscan regions off of the input image, leaving only the exposed portions of the image.

Because the electronic bias level can vary with time and temperature, its value is determined from the overscan region in the particular exposure being processed. A raw STIS CCD taken in full frame unbinned mode will have 20 rows of virtual parallel overscan in the AXIS2, or image *y*, direction, which is created by over-clocking the readout of each line past its physical extent, and 19 leading and trailing columns of serial physical overscan in the AXIS1 or image *x* direction, which arise from unilluminated pixels on the CCD. Thus the size of the uncalibrated and unbinned full frame CCD image is 1062 (serial) by 1044 (parallel) pixels, with 1024 x 1024 exposed science pixels.

Only the serial (physical) overscan is used for the overscan bias level determination; the virtual parallel overscan is not used. A line-by-line subtraction is performed in the following way. An initial value of the electronic bias level, or overscan, is determined for each line of the image, using only the physical serial overscan, and a function, currently a straight line, is fit to these values as a function of image line. The actual overscan value subtracted from an image line is the value of the linear fit at that image line. The initial value for each line is found by taking the median of a predetermined subset of the trailing serial overscan pixels. Currently, that region includes most of the trailing overscan region, however the first and last two pixels are skipped, as they have been shown to be subject to problems, and pixels flagged as bad in the input data quality flag are also skipped. The region used changes with binning or subarray use (see Table 21.2). The mean value of all overscan levels is computed, and the mean is written to the output SCI extension header as MEANBLEV.

In addition to subtracting the electronic bias level, the BLEVCORR step also trims the image of overscan. The sizes of the overscan regions depend on binning and whether the image is full-frame or a subimage. The locations of the overscan regions depend on which amplifier was used for readout. The number of pixels to trim off each side of the image (before accounting for readout amplifier) is given in Table 21.3. The values of NAXIS1, NAXIS2, BINAXIS1, and BINAXIS2 are obtained from image header keywords. Because the binning factor does not divide evenly into 19 and 1062, when on-chip pixel binning is used the raw image produced will contain both pure overscan pixels, overscan plus science pixels and science pixels. The **calstis** pipeline will only calibrate pixel binnings of 1, 2, and 4 in either AXIS1 or AXIS2.

The CRPIX*i* and LTV*i* keywords are updated in the output; these depend on the offset from removing the overscan.

Table 21.2: Raw Image Pixels Used to Determine Line by Line Bias Level

Columns in Raw Image	Binning
2 through 16	Unbinned
2 through 8	All other supported binnings

Table 21.3: Pixels Trimmed During CCD Bias Level Correction for Amp D

Side	Full Image	Subarray Images	Binned Images
Right	19	18	(19 + 1) / BINAXIS1
Left	19	18	NAXIS1 - (1024 / BINAXIS1 - 1) - Right
Top	0	0	0
Bottom	20	0	NAXIS2 - 1024 / BINAXIS2

CRCORR

The CRCORR step is applicable only to CCD data. This step sums the individual CR-SPLIT exposures in an associated dataset, producing a single cosmic ray rejected file (`_crj.fits`). The **ocrreject** task in the **calstis** pipeline is similar to the WFPC2 **crrej** task, except that **ocrreject** uses the input data quality flags to discard pixels from the input images when forming the output image, it outputs an error array for the cosmic ray rejected image using the input error arrays, and it reads the controlling input parameters (`SCALENSE`, `INITIAL`, `SKY`, `SIGMAS`, `RADIUS`, `PFACTOR`, `BADINPDQ`, and `MASK`) from the `CRREJTAB` reference file.

The CRCORR step does the following:

- Forms a stack of images to be combined (the CR-SPLIT or REPEATOBS exposures in the input file).
- Forms an initial guess image (minimum or median).
- Forms a summed CR-rejected image, using the guess image to reject high and low values in the stack, based on sigma and the radius parameter which governs whether to reject neighboring pixels to pixels identified as cosmic ray (see below).
- Performs one or more rejection cycles, using different (usually decreasing) rejection thresholds, producing a new guess image at each iteration.
- Produces a final cosmic ray rejected image, including science, data quality and error extensions, which is the weighted sum of the input images.

- Flags the data quality arrays of the individual (non-CR-rejected) input files to indicate where an outlier has been found (pixels which were rejected because of cosmic ray hits can be identified by looking for data quality bit = 14 in the `_flt.fits` file).

The cosmic-ray-rejected image is created by setting the value at each pixel to the sum of the values of all good pixels in the stack whose values are within plus or minus `sigmas`*noise* of the initial guess image. Deviant (out of range) stack pixels are flagged as cosmic ray impacted by setting their stack data quality flags to 8192 in the input file.

The value of *noise* (in DN) is computed as:

$$noise = \sqrt{\left(\frac{READNSE}{ATODGAIN}\right)^2 + \left(\frac{DN}{ATODGAIN}\right) + (SCALENSE \times 0.01 \times DN)^2}$$

Where:

- DN = the data number of the stack pixel value.
- `READNSE` is the read noise in electrons, read from the primary header.
- `ATODGAIN` is the calibrated conversion from electrons to DN, read from the primary header.
- `SCALENSE` is an input parameter, read from the CRREJTAB calibration reference file.

The `sigmas` parameter is read from the CRREJTAB calibration reference file; `sigmas` is a string, e.g., `sigmas` = `"4,3"`. The number of entries in the string dictates the number of iterations to be performed (in this example two) and the values in the string indicate the value of `sigmas` for each iteration. In this example, stack values that deviate from the guess image value by more than 4*noise* in the first iteration are considered to be outliers and are excluded from the average on the first iteration, and an improved guess image is formed. A second iteration is then performed in which `sigmas` is set to 3 and good stack values disparate by more than +/– 3*noise* from the guess image are excluded when determining the average. In each iteration, if `RADIUS` is >=1, then pixels neighboring rejected pixels are also excluded in forming the average.

`SCALENSE` is a string containing a multiplicative factor in the noise relation. If `SCALENSE` = "2.0", then the term 0.02*value is added to the *noise*. This term accounts for multiplicative effects, such as would be expected if this rejection were applied to Flatfield ed data. It is important to include to properly flag well-exposed regions (such as the centers of stars, where jitter from the telescope may slightly change the pointing from image to image).

The combination of the individual CRSPLIT or REPEATOBS exposures into a single cosmic-ray rejected frame is performed early in the **calstis** flow. The cosmic ray rejection is performed after each exposure has had its data quality file initialized and the overscan bias level subtraction (BLEVCORR) performed upon it, but prior to subtraction of a bias frame (BIASCORR), dark (DARKCORR) and flatfielding of the data (FLATCORR). The CR-rejected, bias level subtracted image is then passed through the remainder of the two-dimensional image reduction (**calstis-1**) to produce a flatfield ed CR-rejected image (`*_crj.fits`). This CR-rejected flatfield ed image is then passed through the subsequent processing steps in **calstis**. If EXPSCORR is set to PERFORM (see below), then the individual flatfielded but not cosmic ray rejected exposures are also produced.

DARKCORR

The DARKCORR step removes the dark signal (count rate created in the detector in the absence of photons from the sky) from the uncalibrated science image. If the science image is a subarray or was binned, the relevant section of the dark reference image must be extracted and binned to match the science image. If Doppler correction was applied on-board for the science data (i.e., if DOPPON = T), the Doppler smearing function is computed and convolved with the dark image to account for the contributions of various detector pixels to a particular image pixel. This applies only to MAMA data taken with the first order medium resolution gratings or in the echelle gratings. The Doppler convolution is done before binning the dark image. The science data quality file is updated for bad pixels in the dark reference file.

The mean of the dark values subtracted is written to the SCI extension header with the keyword MEANDARK. For CCD data, the dark image is multiplied by the exposure time and divided by the `atodgain` (from the CCD parameters table) before subtracting. For MAMA data, the dark image will be multiplied by the exposure time before subtracting; it will also be convolved with the Doppler smoothing function if DOPPCORR is PERFORM.

DOPPCORR

This step is performed only for spectroscopic data taken with the MAMA detectors. When MAMA data are taken in ACCUM mode in the first order medium (M) gratings or the echelle modes, the MAMA flight software corrects the location of each photon for the Doppler shift induced by the spacecraft motion, prior to updating the counter in the ACCUM mode image being produced. Therefore, during basic two-dimensional image reduction of the MAMA data, the darks and flats must be processed with the same Doppler smoothing as the science data prior to application of the reference image.

The first step is to compute an array containing the Doppler smearing function. The expression below gives the computed Doppler shift, where the time *t* begins with the value of the header keyword `EXPSTART` and is incremented in one-second intervals up to `EXPSTART + EXPTIME` inclusive. At each of these times, the Doppler shift in unbinned pixels is computed as:

$$shift = \mathrm{DOPMAG} \times \sin(2\pi(t - \mathrm{DOPZERO}) / \mathrm{ORBITPER})$$

The value of *shift* is rounded to the nearest integer.

STIS/ 21

DQICORR

The DQICORR step takes the initial data quality file output for the science data and bit-wise ORs it with the values in the bad pixel reference file table (BPIXTAB) to initialize the science data quality file for propagation through subsequent steps in **calstis**. If DOPPFLAG=T, **calstis** will combine data quality information from neighboring pixels to accomodate Doppler smearing prior to performing the OR operation with the (unsmeared) science input data quality image. The DQICORR step also appropriately combines data quality flags in neighboring pixels if the images are binned.

EXPSCORR

If the EXPSCORR calibration switch in the header is set to PERFORM, the pipeline will also process the SCI extensions in the `*_raw.fits` files as individual exposures through **calstis**, outputting an intermediate product, `*_flt.fits`. This file contains the individual flatfielded CRSPLIT exposures in successive imsets of a single file. This file will not be passed through the subsequent calibration steps (e.g., spectroscopic reduction), but will be retained as an intermediate data product, to allow users to examine the effects of the pipeline cosmic-ray rejection and to re-perform the cosmic ray rejection and subsequent calibration steps as desired.

FLATCORR

The FLATCORR step corrects for pixel-to-pixel and large-scale sensitivity gradients across the detector by dividing the data by a flatfield image. The flatfield image used to correct the data is created from three flatfield reference files:

- PFLTFILE - This flat is a configuration (grating, central wavelength and detector) dependent pixel-to-pixel flatfield image, from which any large-scale sensitivity variations have been removed (i.e., it will have a local mean value of unity across its entirety). Such configuration dependent flats are expected to be produced infrequently, perhaps once per year.
- DFLTFILE - This file is a *delta flat* which gives the changes in the small scale flatfield response relative to the pixel to pixel flat (PFLTFILE). Delta flats will be taken relatively frequently (approximately monthly, though less frequently for the MAMAs); there will be a single delta flat for each detector, CCD, NUV-MAMA, and FUV-MAMA. They will be used only if needed.
- LFLTFILE - This flat is a subsampled image containing the large-scale sensitivity variation across the detector. It is usually grating- and central wavelength-dependent (for spectroscopic data) and aperture (filter) dependent for imaging data.

To flatfield science data, **calstis** creates a single flatfield image from these three files[1] as described below and then divides the science image by the flat so created. The pixels of the science data quality file are updated to reflect bad pixels in the

1. The rationale for maintaining three types of flatfield reference files rather than a single integrated reference file is described in detail in *STIS ISR* 95-09 “Calibration Plans for Flat Fielding STIS Data.”

input reference files and the errors in the science data are updated to reflect the application of the flat. Blank values of PFLTFILE, DFLTFILE, or LFTFILE in the science data, indicate that type of flat is not to be used.

To create the single combined flatfield file, **calstis** first expands the large-scale sensitivity flat (LFTFILE) to full format. The pixel-to-pixel flat, delta flat, and expanded low-order flat are then multiplied together. For MAMA data, the product of the flatfield images will be convolved with the Doppler smoothing function if DOPPCORR = PERFORM. If a subarray or binning was used, after taking the product of all the flatfields that were specified, a subset is taken and binned if necessary to match the uncalibrated image, and the uncalibrated data are then divided by the binned subset.

GEOCORR

Geometric correction is applicable to all ACCUM mode imaging and spectroscopic data, but imaging data is not currently rectified because suitable reference files do not yet exist.

The method used is similar to 2-D rectification of spectroscopic data (see “X2DCORR” on page 21-29). For each pixel in the output rectified image, the corresponding point is found in the input distorted image, and bi-linear interpolation is used on the four nearest pixels to determine the value to assign to the output. Mapping from an output pixel back into the input images specified by two-dimensional Chebyshev polynomials stored in the format generated by the IRAF **gsurfit** package.

GLINCORR and LFLGCORR

These steps are performed only for the MAMA detectors. The MAMAs are photon counting detectors. At high photon (pulse) rates, the MAMA response becomes nonlinear due to three effects:

- Pore paralysis in the micro channel plates arises when charge cannot flow rapidly enough to replenish channels whose electrons have been depleted due to high local photon rates. This depletion produces a *local* non-linearity. The local count rate is roughly linear up to counts rates of ~200 counts/second/pixel and then turns directly over, showing an inverted V shape. Thus it is not possible to reliably correct for or flag pixels which have exceeded the local linearity limit in the pipeline (because the relation is bi-valued).
- The electronic processing circuitry has a dead-time of roughly 350 nano-seconds between pulses; thus at global count rates (across the detector) of 300,000 counts (pulses) per second, the electronic circuity counts roughly 90% of the pulses.
- The MIE electronics and flight software can process at most 300,000 pulses per second (i.e., it is matched to the expected global count rate performance of the electronic circuitry). At count rates higher than this, the MIE will still count only 300,000 pulses per second—this represents a hard cutoff beyond which no information is available to allow correction to the true count rate.

In practice, at count rates approaching 270,000 counts/sec the flight software begins losing counts due to the structure of its data buffers. Further work is needed to understand this effect.

For subarrays, the hard cutoff limit of the MIE electronics and software will differ from that for full frame processing, but will still be dependent on the total global rate in addition to the rate within the subarray. The **calstis** pipeline currently applies the full frame correction to subarray data.

The global count rate (across the entire detector) is determined as part of the bright object protection sequence and is passed down with the exposure as a header keyword, GLOBRATE in the science header. If either GLINCORR or LFLGCORR is PERFORM, the global count rate will be checked; a correction for global non-linearity applied if GLINCORR is PERFORM, using the parameters GLOBAL_LIMIT, LOCAL_LIMIT, TAU, and EXPAND read from the MLINTAB reference table.

If the value of the SCI extension header keyword GLOBRATE is greater than GLOBAL_LIMIT, the keyword GLOBLIM in the SCI extension header will be set to EXCEEDED; otherwise, GLOBLIM will be set to NOT-EXCEEDED, and a correction factor will be computed and multiplied by each pixel in the science image and error array. The correction factor is computed by iteratively solving GLOBRATE = X * exp (-TAU * X) for X, where X is the true count rate. This algorithm has not yet been updated to account for the linearity effects from the flight software data buffer management.

If LFLGCORR is PERFORM, each pixel in the science image is also compared with the product of LOCAL_LIMIT and the exposure time EXPTIME. That count rate limit is then adjusted for binning by dividing by the pixel area in high-res pixels. If the science data value is larger than that product, that pixel and others within a radius of EXPAND high-res pixels are flagged as nonlinear. Because our understanding of the MAMA processing electronics is currently incomplete, accurate fluxes (global linearity) at count rates exceeding 270,000 count/sec cannot be expected from the **calstis** pipeline.

LORSCORR

This step is performed for MAMA data only. MAMA data are, by default, taken in high resolution mode (2048 x 2048 pixels), in which the individual microchannel plate pixels are subsampled by the anode wires. This mode produces an image with improved sampling but with appreciably worse flatfielding properties (see the *STIS Instrument Handbook* for more details). If LORSCORR is set to PERFORM, **calstis** simply adds the counts in pairs of adjacent pixels to produce images in the native format (or so-called *reference format*) of the MAMA detectors, with 1024 x 1024 pixels.

The binning of the uncalibrated image is determined from the LTM1 and LTM2 keywords in the SCI extension header of the raw data file. LTM*i* = 1 implies the reference pixel size, and LTM*i* = 2 means the pixels are subsampled into high-res format. In this step, if either or both axes are high-res, they will be binned down to low-res. The binning differs from binning reference files to match an uncalibrated image, in that the pixel values in this step are summed rather than averaged.

PHOTCORR

This step is applicable only for OBSTYPE=IMAGING data. For image mode, the total system throughput is read in from the PHOTTAB reference table. The photometric keywords PHOTFLAM, PHOTBW, and PHOTPLAM are computed using a **synphot** routine to determine the inverse sensitivity, reference magnitude, pivot wavelength, and rms bandwidth. Each quantity is written to a keyword in the primary header.

RPTCORR

This step is applicable only for MAMA data. If the number of repeat exposures is greater than one, then **calstis** will sum the final calibrated output file—either the flatfielded data in the case of image mode data (producing a `_sfl.fits` file) or the two-dimensionally extracted data (producing a `_sx2.fits` file) in the case of long-slit data. RPTCORR just applies a straight pixel-to-pixel addition of the science values, bit-wise ORs the data quality files and determines the error as the square root of the sum of the squares of the errors in the individual exposures.

SHADCORR

This step applies only to CCD data, but it is not currently performed. It is designed to correct for shading by the CCD shutter in very short integration time exposures. The STIS CCD shutter is specified to produce exposure non-uniformity less than or equal to 5 milliseconds for any integration time: the shortest possible STIS CCD exposure time is 100 milliseconds. Ground testing has shown that this step is not currently required.

21.4.2 WAVECAL Processing

WAVECORR

This step applies only to spectroscopic data. The purpose of wavecal processing is to determine the shift of the image on the detector along each axis owing to uncertainties in positioning by the Mode Select Mechanism (MSM) and to thermal motions. It requires one or more contemporaneous wavecal (line lamp) observations, taken without moving the MSM from the setting used for the science data.

Basic two-dimensional image reduction (**basic2d**) is first applied to the wavecal. For CCD data taken with the hole in the mirror (HITM) system the external shutter is ordinarily open, so the detector will have been exposed to radiation from both the science target and the line lamp. In this case, the next step is to scale the flatfield ed science image by the ratio of exposure times and subtract it from the flatfield ed wavecal. Two-dimensional rectification (**x2d**, see X2DCORR below) is then applied to the flatfielded (and possibly science subtracted) wavecal.

Because wavecal data are not CR-SPLIT, cosmic rays must be identified and eliminated by looking for outliers within columns, i.e., in the cross-dispersion direction. Since the data have been rectified, the image can be collapsed along columns to get a long-slit integrated spectrum or along rows to get an outline of the slit (in the cross-dispersion direction).

The shift in the dispersion direction is found by cross-correlating the observed wavecal spectrum with a template spectrum. In the cross dispersion direction, edge location is used for medium and long slits, and cross correlation is used for very short, echelle, slits. The long slits have two occulting bars, and it is the edges of these bars that are used for finding the location. Edges are found by convolving the cross-dispersion profile with the array [–1, 0, +1]. The peak in cross correlation and the edge location are obtained to subpixel level by fitting a quadratic polynomial to the three pixels nearest the extremum.

The shifts are initially measured in units of pixels of the wavecal image, but they are then scaled (depending on the binning of the wavecal) to the reference pixel size (unbinned CCD or low-res MAMA). They are subsequently written to the extension header of the 2-D rectified wavecal in the keywords SHIFTA1 (the shift in pixels along AXIS1, or dispersion direction) and SHIFTA2 (the shift in pixels along AXIS2, or spatial direction). The SHIFTA1 and SHIFTA2 keyword values are also copied from the 2-D rectified wavecal file to the flatfielded science extension header. This is the final step performed on the science data prior to 2-D rectification or 1-D extraction of the science data in the pipeline.

Either or both the wavecal file and science file can contain multiple exposures, and the image can drift across the detector over time due to such things as, thermal effects, so it is necessary to select the most appropriate wavecal exposure for each science exposure. Currently, the wavecal exposure nearest in time to a given science exposure is the one selected. Future enhancements may include interpolation of the appropriate shift.

21.4.3 Spectral Extraction

All of the following steps are applicable only to spectroscopic mode data.

BACKCORR

This step applies to one-dimensional spectral extraction only. If the calibration switch BACKCORR is PERFORM the background is calculated and subtracted from the extracted spectrum. The background is extracted above and below the spectrum, and a function is fit to the variation of the background along the spatial axis (AXIS2). The fitting function is restricted to a zeroth or first order polynomial. The polynomial order, BACKORD, is read from the XTRACTAB reference able and written to a header keyword of the same name in the output spectrum table. Average background values (in counts/sec/pixel) are calculated from each background bin, and account for fractional pixel contributions. In the case of BACKORD=0, a simple average of the two background bins is computed. For BACKORD=1, the background value at the center of each pixel that contributes to the extracted spectrum is derived from the linear fit to the background. The background in the spectrum extraction box is totaled and subtracted from the sum of the spectrum box. The total background at each pixel in the output spectrum is written to the output data table.

In general, the background or sky is not aligned with the detector pixels. To accommodate this misalignment, the definition of the background extraction apertures includes not only a length and offset (center-to-center) but also a linear tilt to assist in properly subtracting the background. This tilt is taken into account when calculating the average background in the background extraction boxes.

DISPCORR

Wavelengths are assigned using dispersion coefficients from the reference table DISPTAB when the calibration switch DISPCORR is PERFORM; if DISPCORR is OMIT, no wavelengths are assigned. The DISPTAB table contains dispersion solutions for a defined reference aperture. Offsets introduced by using apertures other than a reference aperture are removed using coefficients in the `inangtab` reference table. In the case of echelle observations, small shifts introduced by the tilt of the spectral features are removed using coefficients in the XTRACTAB reference table.

For MAMA data, offsets of the projection of the spectrum onto the detector in both the spectral and spatial directions are deliberately introduced by offsetting the Mode Select Mechanism (grating wheel) tilts. This is done approximately monthly to assure a more uniform charge extraction from the microchannel plate over time. For MAMA observations, these induced offsets are removed using coefficients in the MOFFTAB table.

The DISPTAB table of dispersion contains coefficients for fits to the following dispersion solution:

$$s = A_0 + A_1 m\lambda + A_2 (m\lambda)^2 + A_3 m + A_4 \lambda + A_5 m^2 \lambda + A_6 m \lambda^2$$

where

- λ is the wavelength in Angstroms.
- s is the detector AXIS1 position.
- m is the spectral order.
- A_i are the dispersion coefficients.

For each pixel in the AXIS1 direction, a wavelength is calculated. First, any modification to the dispersion coefficients due to spectrum offsets must be made. Table 21.4 lists the possible offsets and the appropriate corrections. For each integer value of *s* in the AXIS1 direction, a wavelength is solved for iteratively using the Newton-Raphson method.

Table 21.4: Modifications to the Dispersion Coefficients Caused by Offsets

Correction	Ref Table	Algorithm	Definitions
Incidence Angle	INANGTAB	$A_i = A_i + \sum_{i=1}^{N} c_1(i) \times s$ $A_0 = A_0 + c_2(1) \times s + c_2(2) \times s^2$	A_i dispersion coefficients c_i incidence angle coefficients s aperture offsets in the axis 1 direction calculated as difference of relative aperture centers (arcsec)
MAMA Offsets	MOFFTAB	$A_i = A_i + \sum_{i=1}^{N} o_1(i) \times x_1 + o_2(i) \times x_2$	A_i dispersion coefficients o_i MAMA offset coefficients x_1 MAMA offset (MOFFSET1) (pixels) x_2 MAMA offset (MOFFSET2) (pixels)
Echelle Spectrum Tilt	XTRACTAB	$A_0 = A_0 + y \tan\theta$	A_i dispersion coefficients y axis 2 offset from nominal A2CENTER during spectrum locate process (pixels) θ spectrum tilt angel

FLUXCORR

If FLUXCORR is PERFORM, the raw counts are corrected to F_λ (erg cm^{-2} sec^{-1} Å^{-1}) using the reference files PHOTTAB and APERTAB. Execution of this calibration step requires that wavelengths have been assigned. Corrections for vignetting and echelle blaze are handled within the PHOTTAB reference files. The conversion to absolute flux is calculated as:

$$F_\lambda = \frac{hc}{A_{HST} R_\lambda T_\lambda \lambda \Delta\lambda} N_\lambda$$

where:

- F_λ is the calibrated flux at a particular wavelength. This quantity is also multiplied by the ATODGAIN if the data were obtained with the CCD.
- h is Planck’s constant.
- c is the speed of light.
- A_{HST} is the area of the unobstructed HST primary mirror (45238.93416 cm^2).
- R_λ is the throughput of the STIS instrument configuration at a particular wavelength when a clear full aperture is in place.
- λ is a particular wavelength.
- $\Delta\lambda$ is the dispersion (Å/pixel) at a particular wavelength.
- N_λ is the net count rate at a particular wavelength.
- T_λ is the aperture throughput at a particular wavelength.

The fluxes are correct for a point source only; the flux for extended targets (as extracted from the 2-D rectified image) requires a division by the value of the keyword DIFF2PT.

HELCORR

The correction of wavelengths to a heliocentric reference frame is controlled by calibration switches HELCORR and DISPCORR—if both switches are set to PERFORM then the correction is made. The functional form of the correction (shown below) requires the calculation of the heliocentric velocity (v) of the earth in the line of sight to the target.

$$\lambda_{helio} = \lambda\left(1 + \frac{v}{c}\right)$$

where:

- λ_{helio} is the heliocentric wavelength.
- λ is a particular wavelength.
- v is the component of the velocity of the earth in the direction of the target.
- c is the speed of light.

The derivatives of low-precision formulae for the sun's coordinates described in the *Astronomical Almanac* are used to calculate the velocity vector of the earth in the equatorial coordinate system of the epoch J2000. The algorithm does not include earth-moon motion, sun-barycenter motion, nor light-time correction from the earth to the sun. This value for the Earth's velocity should be accurate to ~0.025 km/sec during the lifetime of STIS. (Note that the uncertainty of 0.025 km/s is much less than the ~2.6 km/s resolution obtained with the STIS high dispersion echelle gratings.) The value of heliocentric velocity, v, is written to the trailer file.

SGEOCORR

This step applies only to MAMA data and is not presently performed. If SGEOCORR were PERFORM, a correction would be applied for the small scale geometric distortions in the MAMA detectors. These distortions are not adequately removed by the dispersion or spectrum or the two dimensional tracings. The corresponding reference file, SDSTFILE, contains the distortion offsets for each pixel in the MAMA image. For one-dimensional spectral extraction, all AXIS2 positions in the input image must be modified by the AXIS2 small scale distortion deltas in the small-scale distortion file. Because we do not interpolate pixels in the dispersion direction for one dimensional spectral extractions, no corrections are made to the AXIS1 positions prior to reading or extracting pixel values. Instead, the AXIS1 deltas are used to correct the assigned wavelengths.

X1DCORR

If X1DCORR is PERFORM, **calstis** will locate a one-dimensional spectrum to extract, and extract and flux calibrate the spectrum.

Locate the Spectrum

The nominal location of the spectrum is specified in the spectrum trace table, SPTRCTAB and is given by (A1CENTER, A2CENTER) from this table. These coordinates are not constrained to be integers. The nominal position along the slit must be modified to include the previously updated position information found in the header. The nominal A2CENTER position of the spectrum (i.e., the position of the target along AXIS2, or the slit direction) is calculated as follows:

$$A2CENTER = A2CENTER + SHIFTA2 + MOFFSET2$$

where the variables are as described in Table 21.2 `sptrctab` also contains the description of the distorted shape of the spectrum. The shape is stored as an array consisting of pixel offsets (in the AXIS2 direction) relative to the nominal center of the spectrum (A2CENTER). This spectrum trace is used to find, and eventually to extract, the 1-D spectrum.

The location of the spectrum is improved by searching in the vicinity of the nominal location of the spectrum by performing a cross-correlation between the distortion vector and the input spectrum image. The search extends for $\pm n$ pixels around the nominal center, where *n* is read from the MAXSEARCH column in the XTRACTTAB table. At each AXIS2 position in the search range (which differs from the nominal center by an integer number of pixels) a sum of the counts along the spectrum shape is formed. This sum is created by adding the value of one pixel's worth of data at each of the AXIS1 pixel positions. The pixel extracted in the AXIS2 direction is centered on the spectrum position (A2CENTER + pixel offset) and may include fractional contributions from two pixels. Quadratic refinement is used to locate the spectrum to a fraction of a pixel.

The final A2CENTER becomes:

$$A2CENTER = A2CENTER + CRSCROFF$$

where CRSCROFF is the offset found during the cross correlation. If the cross correlation fails, the value of CRSCROFF is set to zero, a warning message is written to the output, and the A2CENTER calculated prior to the cross correlation attempt is used as the location of the spectrum. CRSCROFF is written to the output science header.

An alternate method for performing the cross correlation may be employed. In this case a 2-D template is created from the spectrum trace table. The cross correlation is carried out between the 2-D template and input image. Quadratic refinement is used as above to refine the position of the center of the spectrum to a fraction of a pixel.

Extract the 1-D Spectrum

The extraction of the spectrum is defined by a triplet of extraction *boxes* found in the reference table, XTRACTAB. For each pixel in the dispersion direction, **calstis** sums the values in the spectrum extraction box. The extraction box is one pixel wide and has a height determined from the EXTRSIZE parameter in

XTRACTAB, centered on the spectrum. (Remember that we determined the center of the spectrum in the previous step.) The height of the extraction box may include a fractional part of one or two pixels. In the case of a fractional pixel, **calstis** will scale the counts in the given pixel by the fraction of the pixel extracted. Thus, each pixel in the output spectrum consists of the sum of some number (or fraction) of pixels in the input image.

The extraction of the spectrum allows for unweighted or optimal extraction. The extraction algorithm is selected based on the value of the reference table parameter XTRACALG. This flag has possible values of UNWEIGHTED and OPTIMAL. The value of XTRACALG is written to the header of the output spectrum data file. At present, **calstis** performs an unweighted extraction of the 1-D spectra; the optimal extraction algorithm has not yet been implemented. At the end of the 1-D extraction step, a spectrum of gross counts/second is produced.

X2DCORR

This step applies to two-dimensional spectral extraction. If X2DCORR is PERFORM, a two dimensional rectified image will be produced for spectroscopic data. The two-dimensional rectified output image (`_x2d.fits` or `_sx2.fits`) will have a linear wavelength scale and uniform sampling in the spatial direction. The dispersion direction is the first image axis (AXIS1). The size of the rectified image is made somewhat larger (the increase can be substantial for subarrays) than the input in order to allow for variations in heliocentric correction and offsets of the spectrum on the detector. The binning of the output image will be approximately the same as the input. For each pixel in the output rectified image, the corresponding point is found in the input distorted image and bi-linear interpolation is used on the four nearest pixels to determine the value to assign to the output. No correction for flux conservation is applied, as this is accounted for in the flatfield.

Mapping from an output pixel back into the input image makes use of the dispersion relation and one-dimensional trace table. The dispersion relation gives the pixel number as a function of wavelength and spectral order. The one-dimension trace is the displacement in the cross dispersion direction at each pixel in the dispersion direction. Both of these can vary along the slit, so the dispersion coefficients and the one-dimensional trace are linearly interpolated for each image line. Corrections are applied to account for image offset, binning, and subarray. The spectrum can be displaced from its nominal location on the detector for several reasons, including Mode Select Mechanism (MSM) uncertainty, deliberate offsets for distribution of charge extraction for MAMA data, and the aperture location relative to a reference aperture. These offsets are accounted for by modifying the coefficients of the dispersion relations and by adjusting the location of the one-dimensional trace. See also DISPCORR and FLUXCORR, for algorithmic details (the process of dispersion solution, spatial rectification and flux and wavelength calibration is similar for one-dimensional and two-dimensional spectral extracted data).

21.5 Recalibration of STIS Data

Sometimes the default pipeline calibration, performed shortly after the data were obtained from the telescope, is not the best possible calibration for your science program. There are a number of reasons why it may be desirable to recalibrate your data. The most likely reasons include:

- More appropriate reference files have become available since the pipeline calibration was performed. CCD darks, biases, and hot pixel tables are examples of reference files that are updated frequently, but they require some time to be installed in the pipeline. Likewise we expect to be delivering updated sensitivity files during Cycle 7, updated flatfields, updated aperture throughputs, and so on. In short, over the next year or so, we expect regular improvements in reference files as we carry out the initial on-orbit calibration of STIS.
- Contemporaneous CCD flatfields were obtained with the science data for G750L or G750M NIR observations to remove fringing.
- Some steps need to be repeated with different input parameters. For example, you may wish to re-perform the cosmic ray rejection or the 1-D spectral extraction after adjusting the input parameters. The best target and background extraction regions for extracting 1-D spectra can depend on the science goals of the program. In addition, no extraction is currently performed for first-order spectral modes, so GOs with first-order spectra of standard stars will commonly also wish to perform one-dimensional extraction.
- The calibration software has been enhanced; here again we expect frequent updates over the course of the next year (see Chapter 25).

The STIS calibration pipeline was designed to accommodate the need for full or partial recalibration. As mentioned at the beginning of this chapter, **calstis** is re-entrant, so that certain calibration steps can be performed outside of the pipeline, and others can be executed multiple times, depending upon the science goals.

Generally, the calibration switches in the header control the operations that **calstis** performs on the data. There are three basic ways to select which operations are performed during calibration:

- Edit the calibration switches and run the **calstis** task.
- Use one or more of the pipeline subset tasks described below, managing the calibration through task parameters.
- Run the **calstis** sub-tasks at the host level (i.e., outside of IRAF) using the command-line switches and flags to control the processing.

This section describes the first two methods. In the end, the calibration switches in the headers of the calibrated data files will reflect the operations performed on the calibrated data and the reference files used.

21.5.1 Mechanics of Full Recalibration

You have chosen to fully recalibrate your STIS data. There is a certain amount of set-up required for **calstis** to run properly. The operations mentioned in the checklist below will be described in detail in the following subsections:

1. Set up a directory with the required reference files.
   - Determine which reference files are needed and retrieve them from the Archive.
2. Set the environment variable `oref` to point to your reference file directory. *Note:* you must do this before starting an IRAF session!
3. In an IRAF session, update the input data file headers using **chcalpar**.
   - Set the calibration switches to perform the needed steps.
   - Update the reference file names.
4. Run **calstis** or a subset of its constituent tasks.

Retrieve Reference Files

To recalibrate your data, you will need to retrieve the reference files used by the different calibration steps to be performed. The names of the reference files to be used during calibration must be specified in the primary header of the input files, under the section “CALIBRATION REFERENCE FILES.” Note that the data headers will already be populated with the names of the reference files used during pipeline calibration at STScI.

Chapter 1 describes how to obtain the best available reference files from the HST Data Archive using StarView. For each dataset in the Archive, StarView will list both the reference files used in the initial calibration and the ones currently recommended. This list also indicates in the “Level of Change” column how much the reference files used differ from the recommended ones.

If better calibration reference files have become available since the original pipeline calibration, they can be retrieved from the HST Data Archive as explained in Chapter 1. These files might contain updated information about the instrument signatures, such as an updated hot pixel list or a bad pixel table, or an improved background bias level in a bias frame. Note that “new” does not necessarily mean that the data need to be recalibrated. Use the “Level of Change” information provided by StarView to help determine if recalibration is necessary.

The STIS reference files are all in FITS format, and can be in either IMAGE or BINTABLE extensions. The names of these files along with their corresponding primary header keywords, extensions, and format (image or table), are listed in Chapter 2. The (somewhat obscure) rootname of a reference file is based on the time that the file was delivered to the Calibration Data Base System (CDBS).

Edit the Calibration Header Keywords

To edit file headers in preparation for recalibration, use the STSDAS task **chcalpar**. The **chcalpar** task takes a single input parameter—the name(s) of the raw data files to be edited. When you start **chcalpar**, the task automatically determines that the data are from STIS, determines the detector used and whether the observing mode was SPECTROSCOPIC or IMAGING, and opens one of four STIS-specific parameter sets (*pset*) that will load the current values of all the calibration-related keywords. To edit the calibration keyword values:

1. Start the **chcalpar** task, specifying a list of images in which you want to change calibration keyword values. If you specify more than one image, (using wildcards, for example) the task will read the initial keyword values from the first image in the list. For example, you could change keywords for all STIS raw science images in the current directory (with initial values from the first image), using the command:

   ```
   ct> chcalpar o*_raw.fits
   ```

2. After starting **chcalpar**, you will be placed in **eparam**—the IRAF parameter editor; from there you will be able to edit the set of calibration keywords. Change the values of any calibration switches, reference files or tables to the values you wish to use for recalibrating your data.

3. Exit the editor when you are done making changes by typing "`:q`" two times. The task will ask if you wish to accept the current settings. If you type "y", the settings will be saved and you will return to the IRAF `cl` prompt. If you type "n", you will be placed back in the parameter editor to redefine the settings. If you type "a", the task will abort and any changes will be discarded.

The parameter editor screen for STIS MAMA spectroscopy is illustrated in Figure 21.11. The characters "`oref$`" preceding the names of the reference files specify a logical directory for the location of the reference files. The method for setting a corresponding environment variable is given in the next subsection.

Figure 21.11: Editing Calibration Keywords with chcalpar

It is also possible to use **hedit** to update the input file keywords. The example below illustrates how to turn on the bias correction switch and update the name of the bias image reference file for all STIS raw images in the current directory that begin with the characters “o3y.”

```
cl> hedit o3y*_raw.fits[0] biascorr PERFORM up+
cl> hedit o3y*_raw.fits[0] biasfile "oref$new_bias.fits" up+
```

It is dangerous to change keyword values with **hedit** if the keywords reside in the FITS primary header unit, as is the case with all calibration keywords. The correct way to use this task on inherited keywords is to edit the primary header explicitly by appending “[0]” to the FITS file name.

For each task (except **calstis**) it is not necessary to specify which calibration steps to perform in the primary header keywords of the input files. The execution of each step can be specified in the input parameters task of each stand-alone. The only exception is **calstis** where the switches in the primary header control the calibration steps to be performed.

The reference file names for all the stand-alone tasks and **calstis** have to be specified in their corresponding header keywords. See Table 20.5 for the list of reference files that correspond to each executable.

Running calstis in IRAF

Before running **calstis**, you will need to define an environment variable to indicate the location of the directory containing the needed calibration reference files. The names of the calibration files are preceded with the logical path name "`oref$`" in the STIS science headers. Ordinarily you would define this directory in an IRAF session to be, for example., "`/data/vega3/stis/cal_ref`" using the **set** command:

```
cl> set oref "/data/vega3/cal_ref/" # Won't work!
```

Note the trailing slash (/). However, **calstis** and all of its modules are actually foreign tasks and as such do not access IRAF environment variables. Therefore, *before invoking the **cl***, you will need to define an environment variable from the host command line (see below) that is appropriate to your host machine. For Unix systems, the appropriate command for the example above is:

```
% setenv oref /data/vega3/cal_ref/
```

Then start IRAF.

When running **calstis** or any of its modules, you must define environment variables (such as `oref$`) *before* starting the **cl**. It is *not* possible to define them within IRAF using the **set** command, nor is it possible to define them with an escape to the host level, such as: `!setenv oref /data/vega3/cal_ref/`

21.5.2 Rerunning Subsets of the Calibration Pipeline

Selected portions of the pipeline can be executed with special tasks in the STSDAS **stis** package. The tasks that can be simply used in this fashion are listed in Table 21.5 below. See also Table for the association between **basic2d**, **ocrreject**, **wavecal**, **x1d**, and **x2d** and the components of the **calstis** pipeline. When you run these tasks individually, many of the calibration parameters usually read from the reference file can be entered either as command line arguments or via **epar**.

The **inttag** task for TIMETAG data will accumulate selected events from the raw event table, writing the results as one or more image sets (imsets) in a single, output FITS file. You can optionally specify an explicit starting time, time interval, and number of intervals over which to integrate, and the collection of imsets will be written to the output file, simulating a REPEATOBS ACCUM observation. Breaking the data into multiple, short exposures can be useful not only for variables but also to improve the flatfielding when the Doppler shift is significant. Once the images have been created, it is straightforward to process them with **calstis** and to analyze the output image or spectra, as appropriate.

The screen messages that appear when running any **calstis** module are equivalent to the trailer file contents delivered with the data.

Table 21.5: calstis Pipeline Calibration Tasks

Task	Description
basic2d	Perform basic 2-D calibration.
inttag	Integrate TIMETAG event list to form an image.
ocrreject	Combine images, rejecting cosmic rays.
wavecal	Process wavecal images.
x1d	Extract 1-D spectrum.
x2d	Rectify spectral images.

Combining Images to One File

Each calibration task (including **calstis** itself) takes only one science file as input, though it is sometimes useful to perform only part of **calstis**, such as cosmic ray rejection, on a set of images as if they were part of a repeated series. The prescription is to copy the relevant input files to a single FITS file with multiple imsets, per the format described in Figure 20.6 and Figure 20.7, and then run the relevant calibration task on the combined file. (Such a procedure is, in fact, useful for constructing bias and dark reference files for the CCD.) The easiest way to do this, while preserving the correct file format, is to use the **mstools.msjoin** task. For example, to combine two FITS files while removing cosmic rays:

```
cl> msjoin file1.fits,file2.fits big_file.fits
cl> ocrreject big_file.fits combined.fits
```


21.6 Updates to calstis

We expect **calstis** modules to evolve and improve with time, particularly during Cycle 7, as we understand and characterize more fully the on-orbit performance of STIS. It is possible, even likely, that improvements in the **calstis** software will improve the calibration of your data. To determine the version of the software used to calibrate your data, note the value of the CAL_VER keyword in the data header. The following example uses **hselect** to print the rootname, the optical element, and the version of **calstis** for all `_flt` files in the current directory:

```
cl> hselect o*_flt.fits[0] "rootname,opt_elem,cal_ver" yes
```

Watch the Space Telescope Analysis Newsletters (STANs) or consult the STIS WWW pages for any announcement of enhancements to **calstis.** If you are uncertain whether a given enhancement to **calstis** merits recalibrating your data, contact the Contact Scientist for your program. Often, it is instructive to recalibrate and to determine empirically whether the revised calibration files or software affect the scientific interpretation of your data. If you need to upgrade your version of the **stis** package, contact your IRAF system administrator.

Chapter 22
STIS Error Sources

In This Chapter...

In this chapter we discuss the sources of uncertainty in STIS data, and provide pointers to resources beyond this manual for the latest descriptions of our evolving understanding of these issues.

22.1 Calibration Goals

STIS is a new and complex instrument. As of the date of this *Data Handbook*, our understanding of STIS as an instrument, as well as our development and optimization of the pipeline calibration for STIS (both the software and the reference files) is at an early stage.

In Table 22.1 through Table 22.5, we publish the calibration goals for Cycle 7. These are the accuracies we aim to provide to users by the end of Cycle 7 for data taken in supported modes at any time during Cycle 7. That is, at the end of Cycle 7, if you use the most up to date **calstis** calibration software and the most appropriate reference files to recalibrate your data, then these are the accuracies we aim to be able to provide. In the interim, as we obtain and process the on-orbit calibration data needed to produce the reference files to support this level of calibration accuracy, and as we improve the calibration software in tandem, the level of accuracy you will receive in your data will be different (lower) than these values. Information about the accuracies obtainable at any one time and about data foibles will be regularly posted to the STIS WWW page and announced in Space Telescope Analysis Newsletters (STANs) sent via e-mail to the STIS community (see below).

Table 22.1: CCD Spectroscopic Accuracies

Attribute	Accuracy	Limiting Factors
Relative wavelengths—within an exposure	0.1–0.25 pixels	Stability of optical distortion
Absolute wavelengths—across exposures	1.0 pixels	• Thermal stability • Internal versus external illumination • Derivation of wavecal zero point
Absolute photometry	10%	Instrument stability and photometric calibration
Relative photometry (within an exposure)	5%	Instrument stability and photometric calibration

Table 22.2: MAMA Spectroscopic Accuracies

Attribute	Accuracy	Limiting Factor
Relative wavelengths—within an exposure	0.25–0.5 pixels	Stability of small scale geometric detector + optical distortion
Absolute wavelengths—across exposures	1.0 pixels	• Thermal stability • Internal versus external stability • Derivation of wavecal zero point
Absolute photometry	15%	Instrument stability and calibration
Relative photometry (within an exposure)	5–10%	Instrument stability/flat fields

Table 22.3: CCD Imaging Accuracies

Attribute	Accuracy	Limiting Factor
Relative astrometry—within an image	0.1 pixels	Stability of optical distortion
Absolute photometry	5–10%	Instrument stability
Relative photometry within an image	5%	External illumination pattern

Table 22.4: MAMA Imaging Accuracies

Attribute	Accuracy	Limiting Factor
Relative astrometry—within an image	0.25 pixels	Small scale distortion stability
Absolute photometry	15%	Instrument stability and calibration
Relative photometry within an image	10%	Flat fields/external illumination

Table 22.5: Target Acquisition Accuracies

Attribute	Accuracy	Limiting Factor
Guide star acquisition	1–2”	Catalog uncertainties
Following target acquisition exposure	0.2”	Centering accuracy plus plate scale accuracy to convert pixels to arcsecond
Following peakup acquisition exposure	30% of the slit width	Number of steps in scan + PSF

22.2 Calibration Accuracy Resources

We will continue to update information under the “Calibration” area on the STIS Instrument World Wide Web (WWW) page which will help you to understand the accuracy you can achieve with your data at any given time. Among the types of information we provide there are the following.

The STIS web page can be found at:

`http://www.stsci.edu/ftp/instrument_news/STIS/`

The STIS Data Foibles Listing

The “STIS Data Foibles” page provides examples of commonly found data attributes and anomalies that are unique to STIS and that can affect the interpretation of your data. Currently described in this area are:

- Fringing for CCD spectroscopic observations.
- CCD long wavelength detector halo.
- CCD Gain-4 detector noise.
- CCD hot pixels.
- CCD flat fields and “dust motes.”
- NUV-MAMA dark current.
- Optical ghosts and artifacts in imaging mode.
- Optical ghosts and artifacts in spectroscopic modes.
- Echelle inter-order scatter.
- MAMA PSF and LSF halos.

STIS Performance Summaries

On-orbit determined performance summaries will be updated on the web as information continues to become available. Currently we provide information under the Calibration page on:

- Sensitivity measures and accuracies.
- Target acquisitions.

- MAMA detector performance.
- CCD detector performance.
- Point spread functions.
- Line spread functions and spectral resolution.
- Cross dispersion profiles.
- Aperture locations and throughputs.
- Geometric distortions.
- MAMA flat fields.
- Chronographic performance.
- Instrument flexure, thermal stability.
- Dispersion solutions and wavelength zeropoints.

Calibration Accuracy

We plan to maintain an up-to-date listing of the current levels of calibration accuracy provided by the pipeline at any one time, including such things as absolute sensitivity accuracy (by grating and central wavelength when applicable for spectroscopy and by filter for imaging modes), the relative sensitivity accuracies (across grating modes and across wavelengths within a giving grating mode), the aperture throughput accuracy, the absolute and relative wavelength accuracies and the astrometric accuracies, etc.

Pipeline Software History

The pipeline software history listing provides an ongoing log of the changes made to the **calstis** software and the implications for the accuracy of data calibrated with **calstis**. This history is useful if you are trying to decide whether you wish to download a new version of the **calstis** software.

Reference File History

The reference file listing provides a high-level summary of the history of updates to reference files, which can help you decide whether you wish to recalibrate your data.

Cycle 7 Calibration Plan

Here you can see what observations are planned for Cycle 7 calibration and which calibrations have already been taken. We note that all calibration data are non-proprietary. If we have not yet been able to process existing calibration data—especially data that are particularly appropriate for your science—into a reference file or a GO advisory, you can retrieve those datasets and analyze them directly yourself. New information about STIS instrument performance will be announced regularly in the STANs and posted to the STIS Instrument WWW pages.

22.3 Factors Limiting Flux and Wavelength Accuracy

22.3.1 Flux Accuracy

The accuracy to which you can trust the absolute flux calibration of your STIS spectroscopic data at slit center is limited by several factors including:

- The accuracy of the absolute sensitivity calibration of the grating and central wavelength setting. The on-orbit absolute sensitivity calibration is determined by observing a standard star, with known absolute flux calibration, well centered in both wavelength and cross dispersion in a large slit. The STIS spectrum of this star is then extracted over a standard aperture extraction box and the sensitivity required to return the known flux from the star is determined as a function of wavelength. The standard aperture extraction box is large enough to be relatively insensitive to spacecraft jitter and breathing but small enough that the signal-to-noise of a typical stellar spectrum will not be degraded. STIS calibration accuracies are defined for the standard aperture extraction box; the standard boxes are mode dependent and are given in the XTRACTAB reference file.
- The accuracy of the calibration of the aperture throughput for the aperture you are using for your science relative to the aperture which was used for the absolute sensitivity calibration.
- The accuracy to which your source is centered in your slit.
- The size of the extraction aperture you use to measure your flux and the accuracy to which the cross dispersion profile is known in the mode in which you are observing. Because the corrections for the aperture extraction can be large (e.g., 30% in the near-infrared and the far-UV) this effect can be important.
- Bias and background subtraction can add considerable additional uncertainty for faint sources or spectra with significant variations in flux, particularly for the echelle modes.
- The importance of scattering, which can play an important role, particularly in the G230LB and G230MB gratings.

Additional uncertainties arise for flux measurements not at slit and field center. These uncertainties are relevant when, for example, you wish to determine relative fluxes in an extended source along the long slit or when you have used POS TARGs to move a target along the long slit. They include:

- The variation in slit throughput along the slit. The slits have 5 micron (corresponding to ~0.2 arcsecond) variations along their widths, which for a 0.1 arcsecond wide slit on a diffuse source, would produce a 20% variation in flux. For a point source the variation would be more in the 5% range for that same slit. There are also dust specks with appreciably higher opacity along some places in some slits. These specks have not yet been cataloged.

- The accuracy to which the vignetting along the cross-dispersion direction is known for your grating and central wavelength
- The accuracy to which the low-order flatfield along the dispersion direction is known off of field center for your grating and central wavelength.

At this early stage, the accuracies to which these factors are known are changing dramatically, as we finish analyzing the Servicing Mission Orbital Verification (SMOV) data and embark on Cycle 7 Calibration. Updated calibration information is provided on the STIS WWW page.

22.3.2 Wavelength and Spatial Accuracies

The accuracy with which the wavelength scale is known in your calibrated STIS spectrum will depend on several factors:

- The accuracy of the dispersion solutions, which governs the accuracy to which relative wavelengths are known in a given spectrum
- The accuracy of the wavelength zeropoint, which governs the accuracy to which relative wavelengths are known across spectra.
- The accuracy to which your source is centered in the science slit (a pixel of miscentering corresponds to a pixel in absolute wavelength space).

The dispersion solutions used to calibrate STIS on orbit data were derived on the ground during thermal vacuum testing. On-orbit tests confirm the applicability and accuracy of the ground dispersion solutions for on-orbit data, producing relative wavelength accuracies of 0.2 pixels across the spectrum for first-order gratings at the prime settings and appreciably better in some instances. For the echelle modes, at the prime settings, the accuracies are roughly 0.2 pixels for wavelengths in the same order and approximately 0.5 pixels for the entire format. The intermediate wavelength settings have roughly twice these errors.

Due to the lack of repeatability of the Mode Select Mechanism (STIS's grating wheel—see page 19-3), the projection of your spectrum onto the detector in both wavelength and space will vary slightly (1 to 10 pixels) from observation to observation (if the grating wheel is moved between observations). In addition, thermally induced motions can also affect the centering of your spectrum. The **calstis** pipeline removes the zeropoint offsets using the contemporaneously obtained auto-wavecals (see "WAVECAL Processing" on page 21-23). The wavelength zeropoint in your calibrated data (the *rootname*`_sx2.fits`, `_x2d.fits`, `_x1d.fits`, and `_sx1.fits` files) is corrected for these offsets and should have a wavelength zeropoint accuracy of ~0.1–0.2 pixels (better when the wavecal is taken through small slits, worse for those taken through wider slits). This accuracy should be achieved, so long as contemporaneous wavecals were taken along with the science data, distributed at roughly one hour intervals among the science exposures, and assuming the target was centered in the slit to this accuracy or better.

The accuracy of the zeropoint pipeline calibration in the spatial direction is slightly less, roughly 0.2-0.5 pixels. This is because the finding algorithm, which must locate the edges of the aperture for short slits and the edges of the fiducial bars on the slits for the long slits, is less robust. Observers need to be aware of possible offsets between spectra in the spatial direction, particularly when deriving line ratios for long-slit observations of extended targets taken with different gratings.

Chapter 23

STIS Data Analysis

In This Chapter...

In this chapter we discuss the data reduction applications available to work with STIS data, and describe specific analyses you may want to apply to your spectral, timetag, and acquisition data.

23.1 Data Reduction Applications

Most of the *new* software tools for operating on STIS FITS files are contained in two STSDAS packages:

- **toolbox.imgtools.mstools**: Contains image manipulation tasks created especially for STIS and NICMOS image set (*imset*) data and which exploit the error and data quality arrays in their operations (e.g., **msarith**, **mscombine**, **msstatistics**, **mssplit**, and **msjoin**). These tasks are described in “Working with STIS and NICMOS Imsets” on page 3-12.
- **hst_calib.stis**: Contains the STIS specific tasks **basic2d**, **calstis**, **ocrreject**, **wavecal**, **x1d**, and **x2d**.

In addition to the above packages, most basic image manipulation software (e.g., **display**, **daophot**, **imexamine**, **contour**, etc.) and spectral analysis software (e.g., **splot**, **tables**, **specfit**, **igi**, etc.) available in IRAF/STSDAS can be used on STIS data, either directly through the IRAF FITS interface or by converting data to another IRAF format. Chapter 3 includes information about how to display STIS images and extracted spectra as well as how and when to convert data formats and a description of spectral analysis taks. Table 23.1 lists some of the more useful IRAF/STSDAS applications for working with STIS data.

Table 23.1: Spectral Analysis Tasks

Task	Input Formats	Purpose
echplot	3-D tables	Plots multiple STIS echelle spectral orders.
nfit1d	2-D & 3-D tables, images	General 1-D feature fitting; part of the STSDAS **fitting** package.
igi	2-D & 3-D tables, images	General presentation graphics; supports world coordinates.
sgraph	2-D & 3-D tables, images	General 1-D plotting; supports world coordinates.
specfit	1-D images, ASCII tables	General 1-D spectrum modeling package.
splot	*multispec* images	General 1-D spectral analysis.

Some of the tasks are intended for browsing data or producing publication-quality plots: the **igi** and **sgraph** tasks were described in Chapter 3. The **echplot** task is useful for browsing STIS extracted spectra. You can plot single spectral orders, overplot multiple orders on a single plot, or plot up to 4 orders in separate panels on the same page. For example, we overplot the orders contained in rows 2 through 4 and 6 on one page:

```
cl> echplot "stis_x1d.fits[1][r:row=(2:4,6)]" output.igi \
>>> plot_style=m
```

Note that the the `plot_style` parameter governs whether the spectral orders are plotted one per page, overplotted, or plotted one per panel, for parameter values of “s”, “m”, or “p” respectively. The brightness unit is calibrated FLUX by default, though other quantities (e.g., NET counts) can be specified using the `flux_col` parameter.

23.2 STIS-Specific Reduction and Analysis Tasks

In Chapter 21 we discussed the components of the STIS pipeline that can be run as individual tasks. Observers may find that they wish to perform parts of the pipeline reduction again on their data using these tasks. Typical examples will be to re-perform cosmic ray rejection, altering the input parameters or using data from separate datasets, or to perform one-dimensional spectral extraction on long-slit data or to modify the input parameters (e.g., aperture extraction box, or background region) when doing one-dimensional spectral extraction for echelle data. For completeness we list the tasks again below. To run these tasks you need to retrieve the calibration reference files they require from the Archive and set the `oref` parameter appropriately (see “Mechanics of Full Recalibration” on page 21-31). An example of using **x1d** with a user specified extraction box (11 pixels high) and a user specified center (line=500) is given below:

```
cl> x1d o3s41301o_flt.fits 3s41301o_x1d.fits center=500 \
>>> size=11
```

Table 23.2 lists some of the stand-alone tasks for working with STIS data. Consult the on-line help for more information about all these tasks. We expect additional options to become available within the stand-alone (i.e., outside the pipeline) versions of these tasks as we increase the number of parameters which can be changed through **epar** and as we add new functions, such as background subtraction correction for echelle modes and optimal extraction for echelle and first order spectra to **x1d**. Stay tuned to the STANs and WWW.

Table 23.2: STIS-Specific Tasks

Task	Description
basic2d	Perform basic 2-D calibration.
inttag	Integrate TIMETAG event list to form an image.
ocrreject	Combine images, rejecting cosmic rays.
wavecal	Process wavecal images, determine spectral and spatial shifts.
x1d	Extract 1-D spectrum.
x2d	Rectify first-order spectral image.

23.3 Working with Two Dimensional Extracted Spectra

Sensitivity Units and Conversions

Your two dimensional extracted spectrum (`_sx2`, or `_x2d` file) has units of erg cm^{-2} sec^{-1} $Å^{-1}$ $arcsec^{-2}$. The conversion from counts to surface brightness (I_λ) is calculated by the pipeline as:

$$I_\lambda = \text{counts} * \text{gain} * h * c / (\text{exptime} * t_\lambda * A_{HST} * d * m_s * W)$$

where

- gain is the conversion from counts to electrons for the CCD, and is unity for MAMA observations.
- *h* is Planck’s constant.
- *c* is the speed of light.
- exptime is the exposure time.
- t_λ is the wavelength-dependent integrated system throughput divided by the physical area of the HST mirror, which is given in the PHOTTAB reference file table.
- A_{HST} is the physical area of the HST mirror.

- d is the dispersion in A/pixel, derived from the DISPTAB reference table.
- m_s is the plate scale in arcseconds/pixel in the cross-dispersion direction, which is the product of the CD2_2 header keyword value and (3600 arcsec/degree).
- W is the slit width in arcseconds.

The flux from a fully extended continuum source as transmitted by the science slit, over an arbitrary number of pixels in the spatial direction ($Npix_s$) and taken over an arbitrary number of pixels in the wavelength direction ($Npix_\lambda$, where to keep from degrading the spectral purity $Npix_\lambda * m_\lambda$ must be less than W) is given by:

$$\mu(I_\lambda) \times W \times Npix_s \times m_s$$

where:

- $\mu(I_\lambda)$ is the average value of the surface brightness, I_λ, over the $Npix_s * Npix_\lambda$ pixels in the rectangle being integrated.

For an emission line source, the situation is somewhat different. There, the line surface brightness, I_{line}, from an emission line feature, in ergs sec^{-1} cm^{-2} $arcsec^{-2}$ is given as:

$$I_{\text{line}} = \frac{\text{counts} \times h \times c}{(\text{exptime} \times t_\lambda \times A_{\text{HST}} \times m_s \times m_\lambda)} x = I_\lambda \times (W \times d / m_\lambda)$$

where:

- I_λ is as given above (i.e., the values in the `_x2d.fits` or `_sx2.fits` image).
- m_λ is the plate scale in the dispersion direction as given in the CD1_1 header keyword.
- All other parameters are as above.

Having performed this conversion, one can take an average or sum of the value of I_{line} over the extent of a feature to get the mean, $\mu(I_{line})$, or to get the total flux from the line $F_{line} = \mu(I_{line}) * Npix_\lambda * m_\lambda * Npix_s * m_s$ over a $Npix_\lambda * m_\lambda$ by $Npix_s * m_s$ region on the sky, where $Npix_\lambda * m_\lambda$ equals the width of the emission feature in the spectral direction.

The factor $W*d/m_\lambda$ which converts between diffuse continuum source surface brightness and diffuse emission line surface brightness is given in the CONT2EML header keyword and is simply the slit width expressed in Angstroms. The surface area of a pixel in arcseconds ($m_s * m_\lambda$) is given in the header keyword OMEGAPIX.

Finally, the DIFF2PT keyword in the data header gives the conversion factor to flux units in erg cm^{-2} sec^{-1} $Å^{-1}$ for a point source. The DIFF2PT keyword is calculated as:

DIFF2PT = $W * m_s / \overline{A}_{\lambda}$,

where W and m_s are as above and $\overline{A}_{\lambda}$ is the wavelength averaged point source aperture throughput for the science aperture, determined from the APTHRUTAB reference table. That is if you integrate the `_x2d` or `_sx2` file over the full wings for a point source (which can be quite extensive) and multiply by the DIFF2PT parameter you will recover the flux of the point source. Of course, point source observers are better advised to use **x1d** to extract a one-dimensional aperture extracted spectrum from their long-slit first-order data, which will then use the wavelength dependent aperture throughput and the defined point source extraction aperture and calibration, as well as perform background subtraction.

In general we note that the cross dispersion profiles can be quite extended (particularly in the far-UV and in the near-infrared); fluxes derived for extended sources from the `_x2d.fits` files as above assume that the sources are extended on scales which contain the bulk of the cross dispersion flux from a point source. As we make further progress analyzing the cross dispersion profiles and their effect on the accuracies of point source and diffuse source fluxes we will provide updates on the WWW and through the STANs.

See also Chapter 6 of the *STIS Instrument Handbook* for a more detailed discussion of units and conversions for different source types.

23.3.1 Wavelength and Spatial Information

Two-dimensionally extracted spectra have been wavelength calibrated and rectified to a linear wavelength scale. Tasks such as **splot** can work directly on the `_sx2.fits` and `_x2d.fits` files and can read the wavelength header information which is stored in the standard FITS CD matrix keywords. Alternatively you can use these keywords directly to determine the wavelength or distance along the slit at any pixel as:

- λ(x) =CRVAL1+ (x-CRPIX1) * CD1_1
- s(y) = (y-CRPIX2) * CD2_2.

where λ(x) is the wavelength at any given *x* pixel, and s(y) is the distance along the slit from slit center for any given *y* pixel, in units of degrees.

23.4 TIME-TAG Data

As described in “Tabular Storage of STIS Data” on page 20-5, raw time-tagged data are stored in an event table which contains separate columns for the *x* and *y* pixel coordinates and the arrival time of each detected photon event. There will also be an associated table containing “good time intervals.” In general these data can be analyzed in one of two ways:

- Convert the data to QPOE format and use the tasks in the **xray** and **xtiming** IRAF packages to work with the time series data directly.

- Generate a series of ACCUMulated images from user specified time intervals of data and then process the image(s) with **calstis**.

Using Existing PROS Time Series Analysis Software

The PROS **xray** and the **xtiming** packages in IRAF—originally developed to analyze Roentgen Satellite (ROSAT) data—can be used to do time series analysis of the STIS TIME-TAG data. To use this package, the `*_tag.fits` files need to be converted to PROS QPOE format (extension `*.qp`), using the task **fits2qp**. A few particularly useful tasks within the PROS software package are listed in Table 23.3.

Table 23.3: Useful PROS Tasks

Task	Purpose
period	Find period from a dataset
fldplot	Plot the light curve with the period folded into it
chiplot	Chi-square plot for various periods
ltcurv	Plot simple light curve from a dataset

Note that the times given in the first column of the raw time-tag data (which is the time relative to the start of the exposure) are not corrected for the time delay due to the motion of the earth or the spacecraft. The change in time delay due to the motion of the spacecraft can be a maximum of about 30 millisec in one orbit. The absolute time delay relative to the time-frame at the earth barycenter can itself be much larger. To correct for these effects, the ephemeris of the earth and the spacecraft are necessary. A separate task is being developed at present, similar to the tasks for the High Speed Photometer (HSP), to correct for these effects and to convert the times to the barycenter of the earth. This task can be used by observers, or can be processed at STScI as a special request, for those science uses of TIME-TAG where it becomes an important effect.

Using inttag to Produce ACCUM Images of Specified Time Slices

The **inttag** task can be used to integrate STIS TIMETAG data into an image or set of images. The default behavior for **inttag** is to accumulate all events from the table, writing the results as one image set in the output FITS file. The user has the option, however, to specify explicitly a starting time, time interval, and number of intervals over which to integrate, in which case a collection of image sets will be written to the output file, simulating a REPEATOBS ACCUM observation. Breaking the data into multiple, short exposures can be useful not only for variable targets but also to improve the flatfielding when the Doppler shift is significant.

To generate each time-filtered image, **inttag** compares the arrival time for each event to both the user-specified interval and the set of *good time intervals*. (Good time intervals, or *GTIs*, are intervals during which STIS is known to be taking valid data.) If the event qualifies, the raw *x* and *y* coordinates will be mapped to the appropriate output pixel location (to account for binning, subarray location, and Doppler correction for echelle spectroscopy), and the detected photon count of the output pixel will be incremented.

The **inttag** task requires two arguments: the names of the input and output FITS files, in that order. Optional parameters include writing the output image(s) in high-res format (the default is low-res). To specify times interval(s) different from the entire duration of the exposure, specify the starting time in seconds since the beginning of the exposure (`sttime`, the default is INDEF, meaning to start at the beginning of the first GTI), the integration time in seconds (`increment`, the default is INDEF, meaning to end at the last GTI), and the number of intervals (`rcount`, the default is one). If no other value is specified, one ACCUM image set will be created containing all the events. A simple example would be to create a single image set, including only the first 1000 seconds:

```
cl> inttag stis_tag.fits kilo_raw.fits sttime=0 increm=1000
```

A somewhat more complex example is to create 20 high-res imsets, each 100 seconds in duration, starting at the first time in the GTI table. Note that while 20 imsets were specified, fewer may actually be written if any of the 100-second intervals is not contained within any GTI, or if the last time in the GTI table is less than 2000 (i.e. 100 sec * 20 intervals); **inttag** will report how many imsets were created.

```
cl> inttag stis_tag.fits multi_raw.fits sttime=0 \
>>> increm=100 rcount=20 high+
```

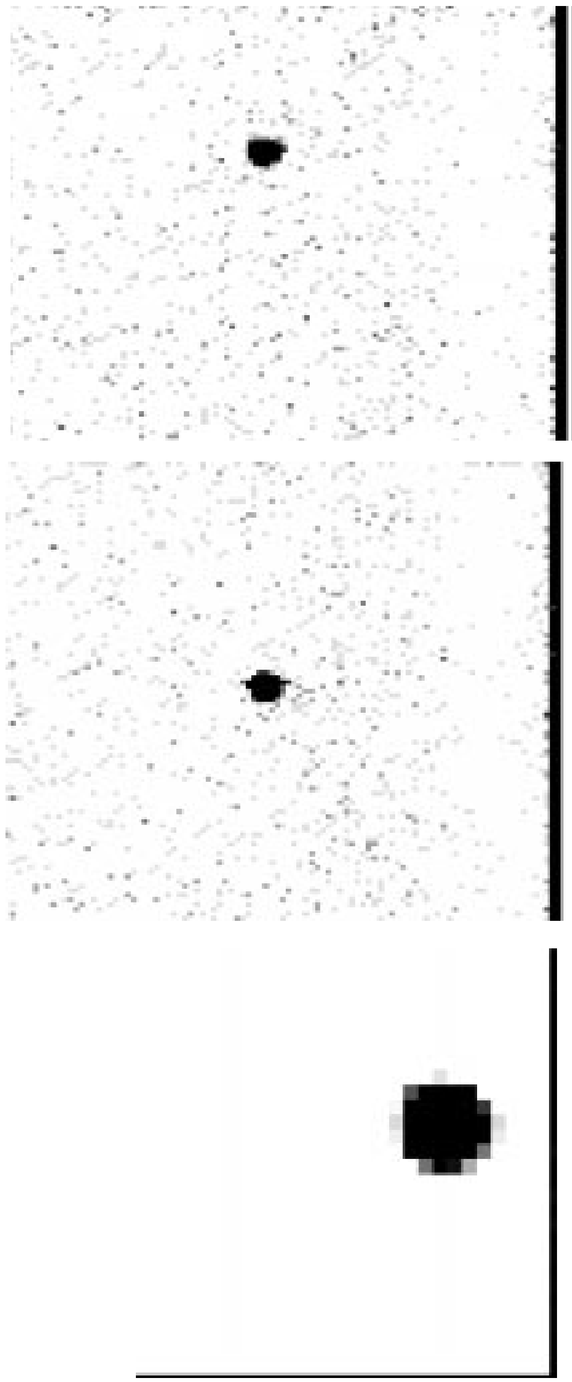
Once the images have been created, it is straightforward to process them with **calstis** and analyze the output images or spectra, as appropriate (see “Recalibration of STIS Data” on page 21-30).

23.5 Target Acquisition Data

Target Acquisition Basics

There are two types of STIS target acquisition: ACQ and ACQ/PEAK; for more details on target acquisition, see *STIS ISR* 97-03. For ACQ observations, there are three parts to the target acquisition data that you receive. The first is an image of the target in the target acquisition sub-array (100 x 100 pixel for POINT sources, user-defined for DIFFUSE sources) based on the initial pointing (see Figure 23.1a); `image_raw.fits[sci,1]`). The software then determines the position of the target with a flux-weighted pointing algorithm and calculates the slew needed to place the target at a reference point in the target acquisition sub-array; for DIFFUSE sources, an option to perform a geometric centroiding is available. An image of the target at this corrected position is then obtained (see Figure 23.1b) `image_raw.fits[sci,2]`)—this is the coarse centering. To perform the fine centering (i.e., to place the object precisely in a slit), an image (32 x 32) of the reference `0.2X0.2` aperture is obtained (see Figure 23.1c) `image_raw.fits[sci,3]`), and the location of the aperture determined. A fine slew is then performed to center the target in the reference aperture, which should be accurate to 0.5 pixels (0.025 arcseconds). A final slew to center the target in the science aperture is performed at the start of the follow-on science observation.

Figure 23.1: Three Stages of an ACQ Observation



a) Initial Star Position in TA Sub-array

b:) Star Position After Coarse Centering

c) Reference Aperture Position (0.2X0.2)

If a narrow slit is used for the science, an ACQ/PEAK acquisition may have been performed. The slit is scanned across the object with a pattern determined by the aperture selected. The telescope is then slewed to center the star in the aperture, and a confirmation image (a 32 x 32 grid) is obtained; the accuracy of the ACQ/PEAK is 5% of the slit width. Note that the last extension in the file (`image_raw.fits[4]`) contains the values in the individual steps of the ACQ/PEAK (use **listpix** to view these values).

When examining the confirmation image, note that the slit will be illuminated by the sky even if no star is present (see Figure 23.2; `image_raw.fits`[sci,1]). To confirm the presence of a star, use the **imexamine** task and make certain that the FHWM is small. For the images in Figure 23.2, the measured values are given in Table 23.4.

Figure 23.2: ACQ/PEAK Confirmation Images

a) Image of the STAR in the 0.1X0.2 Aperture

b) Image of the SKY in 0.2X0.09 Aperture.

Table 23.4: Measured Brightness for STIS ACQ Image

Type	Enclosed	Gaussian	Direct
Star	1.59	1.57	1.49
Sky	15.22	142.84	4.81

ACQ Data

An examination of the target acquisition data (either from the raw data or the paper products) will allow you to detect gross errors in the centering of your target. A comparison of the initial ([sci,1]) and post-coarse slew ([sci,2]) images should show the object moving close to the center of the acquisition sub-array. You can also verify that the fluxes in both images, which are found in pixel 722 of the `_spt` file, are consistent by performing the following steps in IRAF:

```
cl> listpix image_spt.fits[1] | grep 722
cl> listpix image_spt.fits[2] | grep 722
```

The first value will be the target flux in the maximum checkbox (3 x 3 for POINT sources, user-defined for DIFFUSE sources) in the initial image, while the second is the maximum checkbox in the post-coarse slew image. If the fluxes are not consistent, or if the object did not move closer to the center of the array, there is likely a problem with your acquisition.

ACQ/Peak Data

To verify that the ACQ/PEAK worked, examine the flux values at each stage of the peakup (listed in the paper products or in the data file). Comparison of the maximum flux value during the peakup with the flux in the post-ACQ/PEAK confirmation image should show that the flux in the confirmation image was greater than or equal to the maximum flux in the peakup grid. If this is not the case, then there is likely a problem with your peakup acquisition.

Note that you will need to perform two corrections to the data prior to your comparison. When calculating the flux in the confirmation image, you will need to subtract 32768 if the minimum flux value is greater than or equal to 32768. The flux values in the peakup scan also need to be adjusted to add back the minimum flux value that was subtracted prior to processing of the peakup data. This value can be found in pixel 712 of the `_spt` image; to display the value on the screen, do the following in IRAF:

```
cl> listpix image_spt.fits[1] | grep 712
```